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DETERMINATION OF BAKING VALUE OF WHEAT BY MEASURE OF SPECIFIC ENERGY OF DEFORMATION OF DOUGH

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With a foreword by the translator, C. F. Merriam

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Foreword

It was my privilege in 1921 to become acquainted with the author of this paper in his laboratory in Nancy. Consequently, I witnessed some of the early experiments that were being conducted at that time and, in fact, was allowed to make some tests to satisfy myself that the manipulation of the apparatus could be easily learned by one having a fair amount of laboratory experience.

In the latter part of 1925, M. Chopin kindly took me to visit the Paris mills of the Grands Moulins de Paris. There I had the opportunity of seeing the same apparatus which I knew in its experimental state, developed and used as a practical means of controlling the process. In this mill there are two laboratories, one where there is a regular force of trained assistants making routine tests, and another where M. Chopin conducts his development work.

M. Chopin so interested me with what he had to say regarding the problem of supplying flour suitable to the needs of the French bakers, that I am pleased to have this opportunity of translating this contribution he has made to "Cereal Chemistry."

The problem in his country is somewhat complicated by the fact that, depending upon the abundance of the domestic crop, France imports varying quantities of wheat while the quantity exported is relatively small. The wheat brought in from abroad varies considerably in quality, and in the properties of dough made from the flour, and, furthermore, differs greatly from the domestic or colonial product.

Consequently the millers have been met with numerous complaints and were perplexed that flour giving satisfaction in one part of the country was not suitable for another. M. Chopin sets

forth his solution to the problem in a most interesting manner, and it is regrettable that a translation can never be made without losing some quality possessed in the original text.

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In the past many researches have been conducted to determine the factors which influence the value of wheat from the point of view of the baker. These factors are those which affect the development of the loaf and the color and taste of the bread. For a long time it has been known that many varieties of wheat used by the miller yield flours which behave very differently when baked. The essential quality which flour must possess, and that which is of greatest importance in bread making, is its ability to form a well developed and easily digested loaf of light texture.

Bread raising is essentially the transformation of dough from a compact homogeneous mass to a spongy material. This change is the result of two distinct phenomena. The first of these is purely mechanical and consists of the gradual change of form from the original compact mass to a cellular structure, in which the very thin membranes present an enormous total surface. The second of these is bacteriological, consisting of the generation and injection of carbonic acid gas into these cells. This is consequently the source of energy required to cause the dough to undergo this change of form.

The rate at which dough rises has an influence on the development of the loaf. It depends upon the diastatic activity of the flour itself, but this property cannot be considered the factor which primarily determines the baking value of the flour. It is a fact that the baker can greatly affect the speed of rising by the amount of yeast used and the temperature at which the dough is raised; but, nevertheless, his ability to alter the nature of the dough and to modify its elasticity is comparatively limited.

These facts make it evident, in the first place, that the baking value of any particular wheat depends largely upon its plastic properties, which are in turn dependent first, upon the albuminous matter contained, and second, on the intrinsic elasticity of this constituent. Methods which are used to gauge the baking value of a flour or of a wheat, based solely on the gluten contained or more usually the proteins as a whole, are dependent in turn upon the proper evaluation of two factors. The first of these is

the chemical analysis, which may be determined with any desired degree of accuracy. The second, or elasticity, has until now never been determined by any strictly rational means. We shall show in the course of this report that it is the elasticity which has the greater influence upon the characteristics of flour.

Perhaps the most logical method of testing wheat is to mill it and make loaves of bread, maintaining all conditions of milling, kneading, and baking as nearly uniform as possible. Unfortunately, this method requires considerable equipment, and it is often doubtful whether or not the final result has been influenced by lack of uniform conditions, or accidental circumstances which affect the development of the loaf.

When these studies were begun, in 1920, it was thought desirable to investigate the possibility of a substitute for this kind of test, which at best has a doubtful value. It was suggested that it would be possible to make a more direct measure of the plastic properties of the dough, which has a well recognized and definite relation to the process of bread making.

It is advantageous to use dough in the plastic state exactly simliar to the condition in which it leaves the mixer, because thereby a sample is obtained which is exactly representative of the composition of the dough actually used, and also which contains all of the material present in the original flour. Another obvious advantage is that it is relatively easy to obtain a homogeneous dough by a purely mechanical process.

A similar test to that which is proposed cannot, with any certainty, be applied to the gluten alone, because in the dough the gluten exists as an extremely delicate net work extending throughout the entire mass and possessing an elastic strength which is the same in all directions. In order to wash the gluten from the dough, this net work is completely broken up, with consequent change in texture and mechanical properties, so that the resulting material is no longer homogeneous. Furthermore, since this washing requires an extended operation carried out by hand, it stands to reason that the results upon gluten thus extracted depend largely upon the personal equation of the experimenter.

It was our endeavor to simulate in the test as nearly as possible the processes which the dough undergoes in actual bread making. When coming from the mixer, the dough is in a compact state, but during the rising and baking it is transformed into thin membranes, later solidified by the heat of the oven. These membranes divide the bread into innumerable cells filled with carbonic acid gas. If

the loaf is well developed these membranes will have been stretched to the limit to which the dough can exist in a thin sheet, at the same time possessing sufficient tensile strength to withstand the mechanical forces set up during the cooking. The greater the ability that the dough possesses of being drawn to a thin sheet, the more complete will be the development of the loaf.

Thus it appears that the sole mechanical test on dough which corresponds exactly to the deformation which it undergoes in forming a loaf, is one which consists in stretching a test sample from a compact state into a thin membrane until it finally becomes weakened to the point of rupture. This test must be made upon dough itself and not upon the gluten contained in the dough. Furthermore, as an incidental observation in this test, it is possible to measure the tensile strength of the membrane while it is being stretched.

The foregoing considerations led me, in 1921, to invent an extensimeter for dough, a description of which was published by Bailey and Le Vesconte (1924) together with a very complete account of exhaustive tests.

In the meantime, the uses to which this apparatus has been put in the milling industry, particularly in the Grands Moulins de Paris, have led to a number of improvements which I shall describe. As a result of these developments it has been found possible to measure the bread making value of wheat based upon the plastic properties of the dough.

Perhaps it would be well at this point to review briefly the changes that have been made upon the method of procedure and upon the apparatus itself.

Preparation of the Test Sample

The flour is mixed for a given length of time in a mixer having a definite speed and maintained at a given temperature, with sufficient salt water to assure that the total moisture content is always the same regardless of the moisture originally contained in the flour. The result will be a dough having mechanical properties characteristic of the flour to be tested.

A charge of flour amounting to 350 grams is placed in a mixer which is regulated to turn 50 revolutions per minute at a constant temperature of 20° C. If the flour contains 15% moisture, it is mixed with 175 cc. of 2% solution of common salt. It is allowed to mix for seven minutes, after which time the dough is removed, placed in a cylindrical mold and allowed to remain there at a con-

stant temperature of 20° C. for twenty minutes. It is then divided into eight cylindrical portions, or test samples, to be used in the eight tests, which must be made without delay.

Extensimeter for Dough Equipped with Recording Pressure Gauge

The modifications made upon the apparatus have been principally for the purpose of controlling as exactly as possible the size of the sample subjected to the test, to facilitate the determination of tensile strength of the membrane as it is deformed, and to record the pressure of air at any time during the course of the test.

Figure 1 is a simplified sketch of the apparatus in its elementary form.

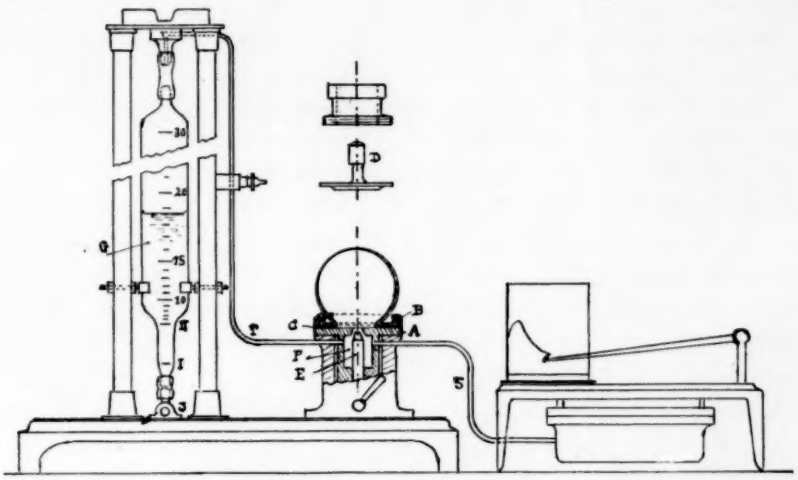

Fig. 1. Diagram of Extensimeter and Recording Pressure Gauge.

As in the earlier model, described previously, the sample is squeezed between two plates, A and B, which are brought together until they strike the stops which control definitely the thickness. 2.6 mm. After removing the cover, D, the central portion, 58 mm. in diameter, which is the part to be subjected to the test, is free to be lifted up and blown into a bubble by pressure of the air admitted through the valve, E. The lower plate is maintained at constant temperature 25° C. by means of an electric heating coil. The central chamber, F, is connected by the tube, S, to a sensitive recording pressure gauge having a range of 100 mm. of water. The drum of the gauge is driven by clockwork at a relatively high speed, and is arranged so that it can be turned back to the same starting point for each test. Air pressure is supplied by

allowing water to flow from an operating bottle into a graduated burette, G, connected at its upper end to the central chamber, F. As the pressure developed is very slight, the water flows from the operating bottle to the burette at a rate which is, for practical purposes, constant and is the same for all tests, so that conditions are exactly comparable.

As soon as the cover is removed, water is allowed to flow from the operating bottle into the burette until the water surface rises from mark I to mark II. The purpose of this is to inject a little air under the sample in order to free it from the lower plate. As the water reaches mark II the drum of the recording pressure gauge is started. As the water continues to rise the test sample swells and takes on the form of a spherical bubble, which continues to increase in size until it is stretched to such a thin membrane that it becomes weakened and bursts.

During this time the pressure gauge has been tracing a diagram such as shown in Figure 2. It will be seen that the pressure reaches its maximum very quickly, but as the dough becomes thinner and thinner its resistance to the pressure of air diminishes, so that the pen draws the Curve, P M, which is practically an equilateral hyperbola. As soon as the operator, observing the rupture of the bubble, shuts off the flow of water into the burette, the pressure immediately drops to zero and the pen describes the final ordinate.

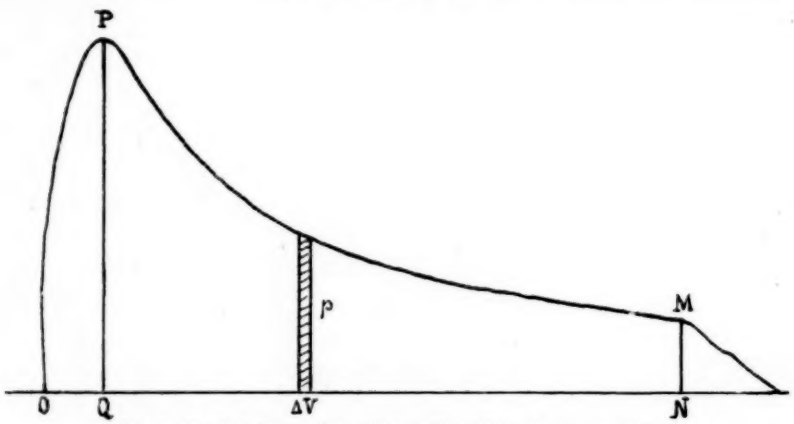

Fig. 2. Typical Curve Traced by Recording Pressure Gauge.

Interpretation of the Diagram

The maximum pressure, P Q, represents the tensile strength of the dough in its initial state. After making correction for the calibration of the pressure gauge, which must be checked before

the test by comparison with a water column, this strength can be expressed in mm. of water. It has been shown in our experiments in 1921 that the amount of water which the baker may add to the mixture is greater when the initial strength of the dough is relatively high.

The elasticity, or coefficient of extension, referred to by Bailey and Le Vesconte (1924), is measured in two ways. As the drum has been turned at a constant speed and the water has risen in the burette also at a constant rate, there is a relation between the length of the diagram, O N, and the volume of air which has been blown into the bubble before bursting. Furthermore, the graduations on the burette offer a direct measure of this quantity. The 1921 experiments show that there was a direct relation between the square root of the volume and the volume to which a loaf of bread can develop in baking. For this reason the burette has etched upon it graduations which read directly in coefficients of extension rather than cubic centimeters.

The final ordinate, M N, is a measure of the strength of the dough at time of final rupture when it has been stretched out to the thinnest sheet that will still hold together. Johnson and Bailey (1924) have shown that when the dough is allowed to ferment its elastic strength decreases. Thus we may consider the final ordinate as the limiting tensile strength approached as fermentation progresses.

The general shape of this diagram is particularly interesting, as it varies widely with the characteristics of the wheat from which the flour has been milled, and, furthermore, is influenced by the method used in milling.

In a complete series of tests, eight separate runs are made, the records of which are superimposed by starting the drum always at the same point. The eight diagrams are then averaged and it should be noted that Figure 2 is really the mean of eight individual diagrams. Figure 3 is a photograph of the results obtained with a good quality of Australian wheat. To complete the working up of the results there remains only to compute the energy which the dough has absorbed in being drawn into a thin sheet.

If we consider first an infinitesimal increase in the volume of the bubble during the course of the test as represented on the diagram by dV., and that P represents the pressure of air inside the bubble at that instant, the work expended by the air upon the dough to produce this infinitesimal deformation is therefore the product PdV. According to the conventional method of repre-

sentation this would correspond to the little cross-hatched area in Figure 2. The total amount of work to which the dough is subjected would therefore be the sum of these infinitesimal areas, expressed:

$$T = \int_{o}^{v} PdV$$

or in other words, the whole area under the curve between the initial starting point and final rupture.

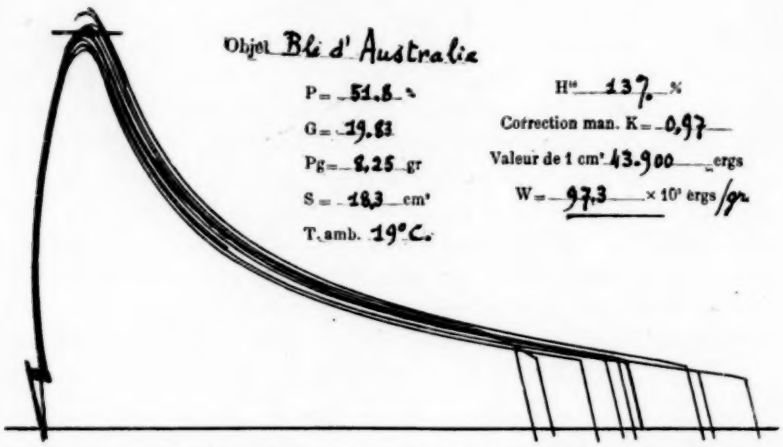

Fig. 3. Specimen Record as Traced with the Recording Pressure Gauge.
Sample: Australian wheat
Moisture 13%
Max. pressure (corrected) 51.8 mm. of water
Gauge correction —0.03 x reading.
Coefficient of extension 19.83
Weight of sample 8.25 gr.
Area of diagram 18.3 sq. cm.
1 sq. cm. is equivalent to 43.9 x 10^3 ergs.

Specific energy of deformation $W = \frac{18.3 \times 43.900}{8.25} = 97.3 \times 10^6$ **ergs/gr.**

Room temperature 19° C.

It will be readily appreciated that since the vertical scale in mm. of water can be converted to dynes per square centimeter, and the horizontal scale can be reduced from centimeters of length to change of volume in cubic centimeters, the area of the diagram represents the work done on the dough sample in

$$\frac{\text{dynes}}{\text{cm}^2} \times \text{cm}^3 = \text{dynes} \times \text{cm.} = \text{ergs.}$$

This can easily be measured by means of an ordinary polar planimeter. In order to reduce this area, expressed in square centimeters

or square inches, to units of work, it is necessary to multiply by a constant which depends upon the relation between the number of cubic centimeters represented by each centimeter of length of the diagram, and also the calibration of the recording pressure gauge, both of which quantities may be easily determined.

As the resulting quantity is the number of ergs required to draw out a sample of dough, the dimensions of which have been arbitrarily chosen, it is desirable to reduce this to a specific quantity referring to either a unit volume or a unit weight. At the end of each test, the bubble is allowed to collapse and then is cut away from the part of the dough which remained clamped between the two plates and therefore was not subjected to the test. The eight are collected and weighed at the end of the series.

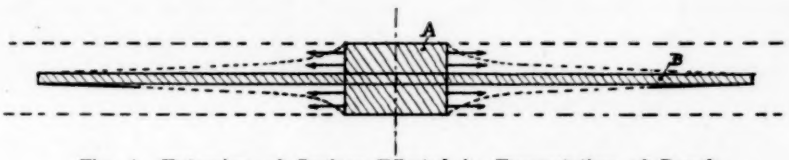

Fig. 4. Extension of Surface Effected in Fermentation of Dough

We can imagine, as shown in Figure 4, a little elementary cylinder having the same height as the thickness, 2.6 mm., of the original sample as it lies on the plate. Suppose, also, that the diameter of the elementary cylinder is such that the weight is q. Let us now imagine this cylinder cut away from the rest of the sample but subjected to tension at the edges so that it is drawn out until it becomes so weakened it is no longer able to withstand the force exerted upon it. Suppose the work required be t, then the specific energy of deformation of the material would be $\frac{t}{q}$, and will be designated in the following by "W".

In order to secure an index for the mechanical properties of flour, the dough has been made under perfectly definite conditions which may be reproduced exactly, and the work required to draw the dough from the original cylinder to the thinnest membrane that will exist without rupture has been measured. Specific energy of deformation is thus defined as the energy expressed in ergs per gram of sample required to inflate the bubble formed in the Chopin extensimeter test.

Let us now consider a bit of leavened dough weighing a gram. As it leaves the mixer, the dough is practically in the form of a united mass, which corresponds to the cylinder A in Figure 4.

The effect of rising is to divide the dough into a great number of cells which are separated from each other by thin membranes. If we imagine these membranes joined together we should have a very thin sheet of great surface, the volume of which would be equal to that of the original bit of dough before rising. This would be represented by the membrane B. The loaf of bread will develop completely if the membrane is stretched sufficiently to accommodate the gas generated, and if at the same time it has sufficient tensile strength to withstand the forces set up in baking. In other words, the specific energy, which depends upon both the tensile strength and the elasticity, should have a proper value.

The specific energy alone, however, is not sufficient in itself to characterize the plastic properties of the flour. The reason is that altho two diagrams may have exactly the same area per unit weight of sample, and consequently give the same specific energy, nevertheless the two flours may behave differently in baking. Consequently it is always necessary to specify in addition the coefficient of extension. Moreover, these two quantities alone have been proved to be sufficient to define the plastic properties of a dough.

The experience of the Grands Moulins de Paris, daily production of 24,000 metric quintals (27,000 barrels) over a period of three years, has established the fact that the coefficient of extension and of specific energy of deformation characterize the baking value of flour. This has been established beyond dispute by observation of flour delivered by their several mills to bakers in widely separated localities. It has been found, furthermore, that for each section of the country there is a definite minimum for both these values below which complaints from the customers begin to appear; that is to say, the type of flour demanded by the bakers is determined in each particular district by the type of wheat grown or imported over a long period of time. It has been found that in almost every case bakers are satisfied—assuming of course that the purity and color are satisfactory—with deliveries having definite mechanical properties which are maintained as nearly constant as possible by this company. Aside from its practical value, this fact has academic interest and confirms what was stated at the beginning, that the baking value of flour depends above all else upon the plastic properties of the dough.

Determination of the Baking Value of Wheats

The foregoing may be applied to tests of wheat as well as to tests of flour simply by performing these tests upon doughs made from flours milled from various kinds of wheat under standard uniform conditions. Experiment has shown that it is possible to obtain varying results by different conditions of milling even when maintaining the same milling yield of flour. In tests to determine the effect of differences in milling, it has been shown that the tensile strength varied inversely with the elasticity, so that after all the variations in the product—that is, the specific energy—are less than for either of the two factors. By using a standard method, however, it is possible to obtain flour having a coefficient of extension and specific energy of deformation which will be characteristic of the wheat tested. The specific energy increases with the percentage of flour produced, so we have adopted 50% (of the wheat) as a standard for our tests. The choice of so low a value was governed by the necessity of leaving the original elasticity of the wheat unaltered. Breaking down of the branny coat, particularly when working with hard wheats, ought not to be carried too far with the test mills generally employed in the laboratory. At the same time, if the milling is not carried far enough the wheat may appear to have a rather large proportion of bran. Table I shows, by way of example, the results obtained with a sample of Manitoba wheat divided into nine lots of 800 grams each. Each of these lots was ground separately and tested. The average of the values of W is 273.9 x 10^3 ergs per gram. The maximum variation from the mean is 5.8%, whereas the average variation is but 2.1%.

TABLE I

Test No.	1	2	3	4	5	6	7	8	9
Coef. of extension	22.7	23.6	21.7	21.4	21.5	21.2	21.8	21.8	21.2
Specific energy of deformation	276	272	283	277	275	258	267	284	273

It has been noticed that the specific energy of deformation for wheats varies between wide limits, the minimum being about 20 x 10^3 for some "Touzelles de Provence," the maximum being as great as 300 x 10^3 for some varieties of Manitoba No. 1. This wide variation shows how necessary it is to consider this factor in determining the baking value of wheat. For the most part these variations are on account of the variable gluten content and also the variations in the elastic properties of the gluten itself. It was

considered worth while to study these variations in W with respect to the percentage of dry gluten contained in wheat.

Fifteen tests were made on different samples of Manitoba Nos. 1, 2, and 3. These gave as an average value: $W = 251 \times 10^3$ ergs per gram and a dry gluten content of 14.35%.

At the same time fifteen tests were made on Algerian wheat from different provinces. These gave as average values: $W = 46.1 \times 10^3$ and a dry gluten content = 11.5%. Comparing these, we see that for Manitoba wheats 251/14.35 = 17.5, whereas for Algerian wheat 46.1/11.05 = 4.2.

It is evident, therefore, that the specific energy of deformation of the gluten alone is four times as great in the first case as in the second. This accounts for the fact that great differences in behavior have been noted between flours containing the same identical gluten content. Flours are most satisfactory to bakers in a given section of the country that have been found to have a definite value for the specific energy of deformation, and it is true that in another section of the country the value which gives satisfaction may be entirely different. Therefore, to furnish flour which will satisfy the customer, the wheat from which it is milled should have a definitely known value of W. As a rule the miller, by taking advantage of the means offered in the Chopin extensimeter as a control for his product, may obtain from a given wheat the form of diagram demanded by his clientele. However, it is not within his power to affect the area of this diagram, as the value of W depends upon the nature of the wheat. For this reason this value is characteristic of the mechanical properties and is the one which is most important to determine.

It has been found as a result of a great number of tests that the value of W for flours compounded from a mixture of wheats may be predicted by the law of mixtures. It may be determined within the limits of commercial accuracy, after correcting for various factors, by the weighted average of the values of W for the respective constituents of the mixture.

Conclusion

The plastic properties of the flour dough are ordinarily rated either by the total protein content or by an estimate based upon personal judgment.

We have shown in this study that it is possible to measure directly certain mechanical characteristics of dough. The only

mechanical test that is comparable with the process which is carried out in the raising of bread is the one described, which consists of drawing out a sample of dough from a compact state into a sheet which is stretched to the breaking limit. Measurements are made of the extent to which it may be stretched and of the tensile strength during the process. The test should be performed upon the dough and not upon the gluten, as the gluten texture is changed by washing and a large element of personal equation is therefore introduced.

By means of a recording pressure gauge a record is made of the variation of pressure throughout the test and from this it is possible to determine the energy required to perform this change upon a unit weight of the sample. This value when stated in conjunction with the coefficient of extension is sufficient to define the plastic properties of dough made from a given wheat or flour.

This specific energy of deformation varies considerably, dependent upon the nature of the wheat, varying as much as four times per unit of gluten content in the example given. Furthermore, the value of W for a mixture is substantially equal to the weighted average of the values for the several constituents.

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WHEAT AND FLOUR STUDIES, IX

DENSITY OF WHEAT AS INFLUENCED BY FREEZING, STAGE OF DEVELOPMENT, AND MOISTURE CONTENT [1]

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Introduction

A committee, consisting of Hayes, Bailey, Arny, and Olson (1917), of the Minnesota section of the American Society of Agronomy, proposed standardized terms to be used in describing the appearance of the wheat kernel. They suggested that descriptive terms be divided into two classes, those having to do with the pigment in the bran layer and those describing the texture. They divide the bran pigment into three subheads: red, light red, and white; and the density into four subheads: corneous, subcorneous, substarchy, and starchy.

Bailey (1915-16) explains that the density of the kernel is "dependent first upon the proportion of pericarp and germ to endosperm and second upon the density of the endosperm. As a general rule, the small kernels which have the larger proportion of bran and germ also have the lower specific gravity."

Millon (1854) determined the density and protein content of various samples of wheat. Pagnoul (1888) and Bailey (1915-16) concluded that high density of threshed wheat was correlated with a high protein content, but Lyon (1905) failed to find such a correlation. In studying the work of the various investigators it was frequently difficult to decide whether a comparison was being made between samples all of which were corneous, or all starchy, or whether the corneous kernels were being compared with the starchy ones. As shown later in this investigation, the previous moisture history of the kernel has a marked effect on its density, and it would be strictly valid to compare the relationship between density and protein content only if the samples of wheat all had the same moisture history. It is doubtful whether we are justified in assuming that a series of wheat samples fulfill this condition.

[1] Published with the approval of the Director.

Numerous investigators have separated wheat from the same sample into corneous and starchy kernels. Church (1867a), considering that starch had a density of 1.53 and gluten a density of 1.38, concluded that the dense grains would contain the most starch and the least gluten. Church (1867b) later found, however, that the corneous kernels separated from the same sample of wheat contained more protein than the starchy ones. This observation has since been confirmed by Nowacki (1870), Wollny (1886), Harper and Peter (1904), v. Feilitzen (1904), Snyder (1904, 1905), Lyon and Keyser (1905), Headden (1916), Roberts (1919), Leith (1919), and Frank (1923a, 1923b). The corneous kernels were also shown to have the greater density by Church (1867a, 1867b), Nowacki (1870), Wollny (1886), Roberts and Freeman (1908), and Roberts (1919).

Frank (1923a) separated 12 samples of hard red spring wheat into 6 portions of increasing hardness as judged by appearance. He found that the protein content increased with increasing hardness in the kernel. The average of the protein content of the 6 fractions separated from the 12 samples arranged in order of increasing hardness he found to be as follows: 10.73, 10.91, 10.91, 11.49, 12.27, and 12.57 per cent. The average protein content of the original samples was 11.71 per cent.

In extending this investigation, Frank (1923b) separated 44 samples of southwestern market-run hard winter wheat into starchy and corneous portions and determined their protein content. A summary of his results is given below.

	Protein content	
	Starchy	Corneous
	%	%
Average	10.68	12.37
Maximum	13.40	14.04
Minimum	9.36	11.08
Range	4.04	2.98

He comes to the following very important altho apparently not generally recognized conclusion: "Within a given sample the dark harder and more vitreous kernels contain relatively more protein, but the yellow kernels in one sample may contain more protein than the darkest, hardest and most vitreous kernels in another sample."

Nobbe (1876) gives the following values for the density of the constituents of the wheat kernel:

Starch	1.53
Sugar	1.60
Cellulose	1.53
Fat	0.91-0.96
Gluten	1.297
Ash	2.50
Water	1.00
Air	0.001293

Church (1867a) mentions the interstitial air as a factor in the density of wheat. Nowacki (1870) and Wollny (1886) recognized by means of the microscope the presence of air spaces in the wheat kernel. They explain that if protein fills the spaces between the starch grains the kernel is corneous, but if air is present in these spaces the kernel is starchy and opaque. Cobb (1904) concluded from his microscopic observations that a high nitrogen content is correlated with small endosperm cells filled with small starch grains. Lyon and Keyser (1905) found that the corneous kernels contained smaller starch grains and fewer vacuoles than did the starchy grains. Roberts (1919) measured the size of the starch grains in corneous and starchy kernels and concluded that the starch grains were larger in the corneous kernels.

The density of wheat harvested at various stages of growth is an interesting point which has received some attention. Nowacki (1870) made determinations on both fresh threshed kernels and kernels from the same stage of maturity which were allowed to air dry before threshing. His data are given below.

Stage of development	Date	Water content		Specific gravity		Dry weight per kernel	
		Fresh	Air dry	Fresh	Air dry	Fresh	Air dry
	July	%	%			mgm.	mgm.
Milk	9	51.47	11.82	1.2004	1.4019	28.5	29.7
Milk	13	47.69	11.67	1.2295	1.3997	35.8	37.0
Yellow ripe	20	25.73	11.61	1.3363	1.3967	41.8	42.2
Yellow ripe	23	12.97	11.57	1.3913	1.3862	42.2	41.9

In studying the specific gravity of wheat harvested at various stages of development and cured under different conditions, Nowacki (1870) concluded that the specific gravity decreased in a rather exact proportion as the number of starchy kernels in the sample increased. There was a distinct tendency for the small heads to contain a larger proportion of starchy kernels than the large heads.

Brenchley and Hall (1908-10) studied the specific gravity of freshly threshed kernels at various stages of growth. They found that the specific gravity decreased for the first four or five three-day periods, after which there was a continual rise up to and after the date of cutting. From these data and the percentage of water in the kernel they calculated the specific gravity of the dry matter of the kernel. They found that the specific gravity of the dry matter decreased from the time of flowering until about the twenty-second day, after which it remained constant. They present their data in the form of a curve which indicates that the specific gravity of the dry matter is at first about 1.90 and gradually decreases to about 1.50 and then remains constant.

Thatcher (1915) studied the development of Velvet Chaff, Fife, and Bluestem varieties of wheat. In his experiments the weight per kernel ranged from 6.34 to 27.95 mgm. and the specific gravity from 1.4045 to 1.4367. He found an apparent correlation between the carbohydrate-protein ratio of the material in the kernel and the specific gravity.

Fryer (1921), in his study of the effect of frost, found that freezing did not affect the density of oats but did decrease the density of wheat, especially the immature sample which he investigated.

Very few investigators have taken into account the moisture content of the wheat when making density determinations. Pagnoul (1888) calculated the density of the dry matter of the kernel from the density and moisture content of the air-dry wheat. Nobbe (1876) gives some data on the effect of the moisture content of the wheat on its specific gravity. The specific gravity was determined at three moisture levels; the results obtained were:

Air-dry (9.42% water) 1.3800
Water-free 1.4085
Moist (27.03% water) 1.2820

Many different methods have been used for determining the density and specific gravity of threshed wheat. A method frequently used to separate a sample of wheat into two parts of different density was to throw the wheat into a liquid which had an intermediate density. In such a liquid some of the kernels would rise and others would sink. The general procedure in most methods was to determine the volume of liquid displaced by a definite weight of wheat. In some cases the liquid chosen would penetrate the wheat, thus causing an error. Also, many investigators failed to free the crease and brush of air. Pagnoul (1888), in a study of 70

different samples of wheat, showed clearly that if the occluded air is not removed from the kernels the results can hardly be considered comparable with the true density of the wheat, for the volume of occluded air is not the same in all cases. Bailey and Thomas (1912) found that the density of a number of samples determined without the removal of the occluded air did not necessarily run parallel to the true density of the samples.

Bailey and Thomas (1912) recommend toluene as the most suitable liquid for use in determining the density of wheat for the following reasons: (1) low density, (2) low surface tension, (3) low volatility, (4) physical constants are not easily altered, and (5) it is a non-solvent for the kernel. They used a pycnometer with a thermometer ground in the neck of the bottle for a stopper and with a side arm attached which could be closed with a ground-glass cap. They cooled the bottle containing the wheat and toluene below the temperature at which the density was to be determined and then warmed the bottle slowly and capped the overflow side-arm tube when the desired temperature was reached. They removed the air from around the kernels and from the crease by suction after the kernels had been placed in the bottle and had been covered with toluene.

Method of Determining Density

The determinations reported in this paper were all made at 25° C. Pycnometers of the Gay-Lussac type were used which had a volume of approximately 25 cc. Usually 10 grams of wheat to the nearest kernel was taken. Weighings were made to the nearest 0.5 milligrams. The wheat was placed in the pycnometer and sufficient toluene was added to cover the wheat. Five determinations were usually carried out at one time. The five pycnometers were placed in a crystallizing dish and the dish was placed in a vacuum desiccator. Pressure was reduced by means of a large water-section pump. The pump was allowed to run 10 minutes. While the material was under reduced pressure the desiccator was moved on the desk with a rotating motion which shook the kernels thoroly with the toluene. The shaking process was performed twice while the material was under reduced pressure. The pycnometers were then completely filled with toluene and were placed in a water thermostat kept at 25° C. After 10 minutes the

volume was adjusted and the pycnometers were weighed. The density was calculated from the following equation:

$$\text{Density} = \frac{(\text{Wt. of wheat})\ (\text{Density of toluene})}{(\text{K} + \text{Wt. of wheat}) - \text{A}} \qquad (1)$$

where K is the weight of the pycnometer when filled with toluene and A is the weight of the flask containing the wheat and toluene. Several different samples of toluene were used, the density of which varied from 0.8599 to 0.8605 at 25° C. The density values were not corrected for the volume of air displaced, i. e., to weight in vacuuo.

The density of the moisture-free wheat was calculated from the density of the wheat containing moisture, and the percentage of water and dry matter by the use of the following formula:

$$\text{Moisture free density} = \frac{(0.9970)\ (\text{D})\ \left(\frac{\%\ \text{dry matter}}{100}\right)}{0.9970 - (\text{D})\ \left(\frac{\%\ \text{moisture}}{100}\right)} \qquad (2)$$

where D is the density of the wheat containing moisture and 0.9970 is the density of water at 25° C. Pagnoul (1888) also calculated his density values to the moisture-free basis.

Experimental

Studies were made of the density of wheat harvested at different stages of maturity; only the heads of the wheat being gathered. The heads from each stage of development were divided into two parts, one part was at once spread out to dry and the other was frozen and then spread out to dry. The samples collected in 1922 were spread in trays in the sun to dry and the freezing was accomplished by placing the sacks containing the heads in a can which was immersed in the brine of an artificial ice plant. The data obtained with these samples are given in Tables I and II. While a thermometer placed in the center of the sack indicated a temperature of −3° to −4° C. and the brine was maintained at a temperature of about −12° C., yet, after this treatment, the appearance of the kernels indicated that they had not been severely frozen.

The next year, 1923, the procedure was modified.

The drying was done on the floor of a large, well ventilated room; while the freezing was accomplished by placing the sacks in the hardening room of an ice cream manufacturing plant, where

the temperature was about −20° to −28° C. In this latter case, there was no doubt that the kernels were frozen, as indicated by their appearance.

TABLE I

KANRED WINTER WHEAT, CROP OF 1922

Density of Frozen (F) and Non-Frozen (NF) Wheat Harvested at Various Stages of Maturity, Freezing Temperature −3° to −4°C.

Lab. No.	Time from first sample	Moisture content at time of harvest	Dry weight per kernel	Protein content, dry basis	Moisture content air-dry wheat	Weight per measured bushel	Density of air-dry kernels	Density calculated to the moisture-free basis
	days	%	mgm.	%	%	lb.		
S-1NF	0	....	....	13.53	8.06	42.2	1.4322	1.4891
S-2F	0	....	....	12.49	7.44	48.6	1.4456	1.4999
S-3NF	2	57.0	20.3	11.90	7.66	50.7	1.4440	1.4997
S-4F	2	57.0	....	11.98	8.14	50.0	1.4408	1.5000
S-5NF	4	54.2	24.5	11.80	9.51	56.1	1.4364	1.5065
S-6F	4	54.2	....	11.50	9.70	55.9	1.4369	1.5084
S-7NF	6	51.9	27.9	12.26	9.12	57.0	1.4407	1.5081
S-8F	6	51.9	....	11.91	9.74	57.3	1.4331	1.5041
S-9NF	8	54.0	27.1	11.66	9.26	59.9	1.4302	1.4965
S-10F	8	54.0	....	11.05	9.54	60.7	1.4353	1.5050
S-11NF	11	49.6	32.1	11.06	9.65	60.9	1.4258	1.4945
S-12F	11	49.6	....	11.50	10.20	61.1	1.4236	1.4963
S-13NF	13	43.8	36.3	11.15	9.39	61.7	1.4276	1.4946
S-14F	13	43.8	....	11.32	9.70	61.8	1.4261	1.4952
S-15NF	15	41.3	36.1	11.37	9.42	62.1	1.4346	1.5031
S-16F	15	41.3	....	11.03	9.54	62.3	1.4298	1.4983
S-17NF*	18	39.7	37.1	11.46	10.93	61.2	1.3942	1.4659
S-18F	18	39.7	....	11.39	11.03	61.3	1.3968	1.4699
S-19NF	20	32.2	39.3	10.18	10.29	61.6	1.4125	1.4833
S-20F	20	32.2	....	10.34	9.96	61.9	1.4192	1.4890
S-21NF	22	18.7	40.6	11.22	9.77	62.3	1.4261	1.4957
S-22F	22	18.7	....	11.43	10.55	61.3	1.4126	1.4856
S-23NF	25	15.4	41.3	12.04	10.32	61.9	1.4099	1.4804
S-24F	25	15.4	....	12.29	9.46	61.7	1.4107	1.4745
S-25NF	32	10.3	37.4	11.42	9.38	61.1	1.4188	1.4838
S-27NF	63	....	....	10.92	8.64	57.5	1.3817	1.4341

*Main part of the field harvested.

Other data obtained with this series of samples are given by Sharp (1925, 1926) and Whitcomb and Sharp (1926) and germination tests carried out on the 1923 series are given by Whitcomb and Sharp (1925).

Table I contains the density data obtained with Kanred winter wheat of the 1922 crop. It was not possible to start sampling this wheat at an earlier stage of development. During the period of development of the wheat studied, the moisture content of the freshly threshed immature kernels decreased from 57 per cent to 10 per cent. The dry matter content of the kernels doubled and the weight per bushel increased materially. On the whole, the protein content remained about constant, altho the results indicate a slight decrease at the beginning of the series and perhaps a slight increase toward the end. The density and weight per bushel were determined with the wheat containing the moisture

content indicated in the table. The calculated density of the dry matter is indicated in the last column. The density of the air-dry wheat decreased as the kernel developed. This decrease is easily explained by the fact that the percentage of yellow berry kernels in the samples also increased as the kernel developed. Yellow berry kernels have a lower density than corneous ones from the same sample. There was no apparent difference in density between the frozen and the non-frozen samples. Samples S-17 and S-18 probably owed their lower density to the fact that they contained more moisture than the other members of the series. Sample S-27 was collected after the straw had broken down and after the wheat had been exposed to rain. The reason for the low density of this sample will be made clear from the facts brought out in the latter part of this paper. The calculated density of the dry matter, with the exception of the first sample, is fairly uniform down to sample S-17, and from there on it is a little lower and more irregular.

TABLE II

MARQUIS WHEAT, CROP OF 1922

Density of Frozen (F) and Non-Frozen (NF) Wheat Harvested at Various Stages of Maturity
Freezing Temperature −3 to −4°C.

Lab. No.	Age of kernel	Moisture content at time of harvest	Dry weight per kernel	Protein content, dry basis	Moisture content, air-dry wheat	Weight per measured bushel	Density of air-dry kernels	Density calculated to the moisture free basis
	days	%	mgm.	%	%	lb.		
S-105NF	13	70.7	7.9	12.60	8.25	42.4	1.4257	1.4830
S-106F	13	70.7	....	12.69	13.90	41.0	1.4181	1.5218
S-107NF	15	66.1	11.5	12.48	9.21	45.8	1.4241	1.4889
S-108F	15	66.1	....	12.55	9.24	44.8	1.4251	1.4903
S-109NF	17	61.5	14.5	12.02	8.46	48.0	1.4266	1.4858
S-110F	17	61.5	....	12.07	9.16	47.2	1.4265	1.4913
S-111NF	20	57.7	17.7	11.67	9.71	51.7	1.4248	1.4936
S-112F	20	57.7	....	11.21	8.94	52.6	1.4299	1.4935
S-113NF	22	52.4	20.7	11.11	8.79	54.7	1.4294	1.4917
S-114F	22	52.4	....	11.53	9.06	55.2	1.4255	1.4894
S-115NF	24	50.9	25.2	11.64	8.83	57.5	1.4266	1.4888
S-116F	24	50.9	....	11.85	8.84	57.0	1.4290	1.4916
S-117NF	27	47.5	26.9	12.09	8.65	59.7	1.4272	1.4881
S-118F	27	47.5	....	12.23	8.08	59.4	1.4314	1.4885
S-119NF*	29	43.3	30.6	12.29	8.26	61.0	1.4316	1.4902
S-120F	29	43.3	....	12.04	8.41	59.4	1.4347	1.4950
S-121NF	31	42.5	29.5	12.73	8.38	60.7	1.4296	1.4887
S-122F	31	42.5	....	13.25	10.54	59.6	1.4206	1.4954
S-123NF	34	36.1	30.5	13.31	8.52	61.2	1.4279	1.4878
S-124F	34	36.1	....	13.35	8.89	59.9	1.4272	1.4899

*Main part of field harvested.

The data in Table II are for Marquis spring wheat of the 1922 crop. This series includes a greater range in development than does the series reported in Table I. The moisture content of the threshed, immature kernels decreased from 70 per cent to 36 per cent. The dry matter content of the kernels increased from about

8 to 30 milligrams per kernel. The weight per bushel also showed a marked increase. The protein content fell slightly during the middle period of development and was slightly higher at the end than at the beginning. The density of the kernel was more uniform throughout than in the series represented in Table I. It is possible to account for the decrease in density toward the end of the series presented in Table I by the fact that the proportion of yellow berry increased toward the end of the series, while the samples presented in Table II were nearly free from yellow berry.

The study of the effect of freezing on the developing wheat kernel was repeated with Marquis spring wheat in 1923. Some of the data obtained are presented in Table III. The range of development studied is about the same as in Table II. The weight per kernel, as given in Tables I and II, was calculated from the kernels used in determining the moisture content of the freshly threshed kernels, while the weight per kernel given in Table III was obtained from the weight of 1000 kernels taken from the threshed air-dried material. The weight per kernel is expressed on the moisture-free basis in all three tables. The protein content of the wheat, as shown in Table III, increased somewhat as the kernel developed and is considerably higher than that shown in Tables I and II. The weight per bushel is also somewhat greater. In Table III the effect of freezing on the density of the kernel is very apparent in the earlier stages of development, the density of the frozen air-dry kernels being greater than that of the non-frozen kernels. The density of the non-frozen kernels is very uniform throughout the whole stage of development studied. There is a rather marked difference in weight per measured bushel between the frozen and the non-frozen wheat at the earlier stages of maturity. At the first three stages of development studied, the frozen wheat weighed more per measured bushel than did the non-frozen wheat. From this stage to the last pair of samples studied the condition was reversed, the non-frozen samples weighing the most, perhaps because the blistered or wrinkled bran layer kept the frozen kernels apart.

The calculated density of the dry matter of the kernel is given in the last column. In the next to the last column is given the experimental moisture-free density. The density values in this column were determined on the wheat dried in a vacuum oven at 100° C. It will be seen that the density of the moisture-free material determined experimentally differs markedly from the calculated value and is nearly the same as that for the air-dry wheat. The first few samples of frozen wheat were considerably less dense after

TABLE III

MARQUIS WHEAT, CROP OF 1923

Density of Frozen (F) and Non-Frozen (NF) Wheat Harvested at Various Stages of Maturity, Freezing Temperature -20 to -28°C.

Lab. No.	Approximate age of kernel	Moisture content at time of harvest	Dry weight per kernel	Protein content, dry basis	Moisture content, air-dry wheat	Weight per measured bushel	Density of air-dry kernels	Density of vacuum dry kernels	Density calculated to the moisture-free basis
	days	%	mgm.	%	%	lb.			
S-131NF	13	69.4	7.68	16.13	9.03	40.0	1.4180	1.4201	1.4800
S-132F	13	69.4	9.15	14.59	9.39	46.5	1.4245	1.2864	1.4908
S-133NF	17	62.5	14.04	15.02	8.61	48.4	1.4167	1.4180	1.4768
S-134F	17	62.5	13.88	14.49	8.41	53.3	1.4310	1.3739	1.4905
S-135NF	21	56.2	19.50	15.40	7.92	56.8	1.4180	1.4112	1.4714
S-136F	21	56.2	20.57	15.19	7.10	59.3	1.4307	1.4257	1.4799
S-137NF	25	50.6	25.28	15.77	7.44	61.7	1.4171	1.4208	1.4667
S-138F	25	50.6	24.50	15.10	7.07	60.7	1.4268	1.4278	1.4752
S-139NF	27	46.5	25.67	16.19	7.08	62.2	1.4176	1.4156	1.4647
S-140F	27	46.5	25.66	16.18	7.32	60.2	1.4208	1.4233	1.4701
S-141NF	29	46.5	26.77	17.00	7.24	62.5	1.4163	1.4189	1.4643
S-142F	29	46.5	27.53	17.29	7.22	60.4	1.4236	1.4277	1.4726
S-145NF*	33	43.5	29.89	16.73	7.31	63.4	1.4157	1.4189	1.4642
S-146F	33	43.5	29.07	17.08	7.06	61.6	1.4179	1.4228	1.4649
S-147NF	35	38.7	30.67	17.08	7.02	63.2	1.4168	1.4202	1.4634
S-148F	35	38.7	30.85	16.70	6.93	61.3	1.4179	1.4226	1.4640
S-149NF	38	34.1	30.19	16.98	7.00	63.5	1.4135	1.4187	1.4593
S-150F	38	34.1	32.66	17.06	7.41	62.4	1.4127	1.4152	1.4615
S-151NF	41	....	31.01	17.81	7.55	63.3	1.4153	1.4135	1.4656
S-152F	41	....	32.07	17.03	7.45	63.3	1.4123	1.4117	1.4613
S-153NF	53	9.3	.....	16.65	8.89	62.8	1.4156	1.4170	1.4760
S-155NF	†	....	.....	.....	8.97	63.5	1.4204	1.4258	1.4824

*Main part of field harvested.
†Shock.

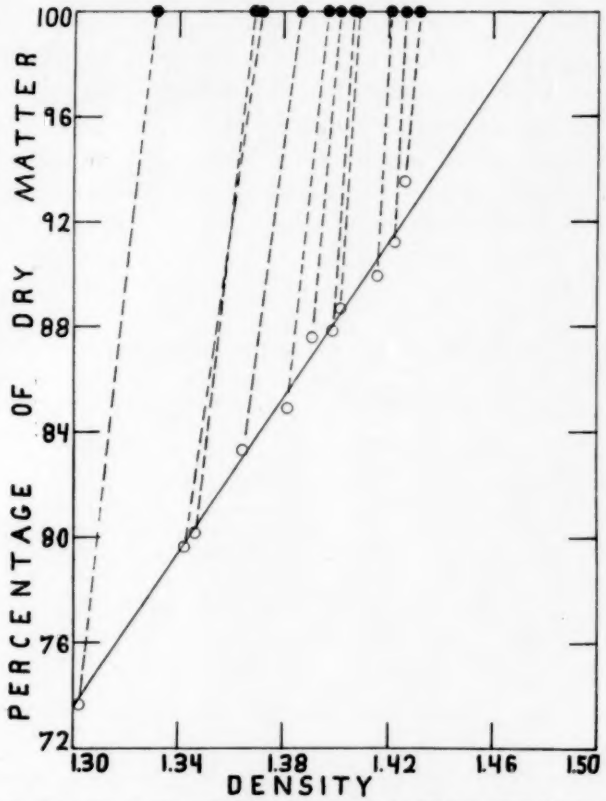
vacuum drying than in the air-dry condition. If we compare the density of the air-dry, non-frozen wheat in Table III with the density of the wheat in Table II, we note that altho they are of the same variety, yet the wheat in Table III, with a protein content ranging from 16 to 17 per cent, has a lower density than that in Table II with a protein content of 11 to 13 per cent. The Kanred wheat in Table I, which has a still greater density, especially in the earlier stages of development when it is not influenced by yellow berry, has a protein content of 10 to 12 per cent. In this instance, at least, the wheats with the higher protein content do not have the greater density. Thus, there must have been some other factor aside from protein content which affected the density in these three series of samples.

In examining the density data presented in Tables I and II, it was thought that perhaps the low densities of some of the samples of air-dry wheat might be due to their high moisture content; and as calculating the moisture-free density did not remedy their inconsistencies, an investigation of the effect of moisture on the density of the wheat kernel was undertaken.

A quantity of Marquis wheat was divided into several portions and the moisture content of these portions was so adjusted as to make a series ranging from 73.58 to 93.52 per cent of dry matter. The density of these portions was determined. They were then dried in a vacuum oven at 100° C. and the density was again determined. The density of the dry matter was calculated from the density of the portions containing the various amounts of moisture. The results are given in Table IV and Figure 1. It will be seen from an examination of these data that the density of the wheat decreases in a uniform manner as the moisture content increases, and that the line extrapolated to 100 per cent dry matter indicates a density of about 1.484 for the moisture-free material. This value is in good agreement with some of the density values calculated for the dry matter from the dry matter contents, ranging from about 85 to 91 per cent. Outside of this moisture range the density calculated for the moisture-free material is too low.

The densities of the vacuum-dried material when plotted against the moisture content before drying also fall on a straight line. It will be noted that after the moisture content of the once air-dried wheat has been increased and the moisture again removed, the wheat does not regain its former high density but has a lower density, depending on the amount of moisture taken up. These observations account for the low density of sample S-27, in Table I. The

samples in the lower part of Table IV were markedly changed in appearance after drying, as compared with the original sample. They were opaque, while the original sample of wheat from which they were produced was corneous. Later work has shown that when corneous kernels were increased in moisture content to between 18 and 25 per cent and the moisture was again removed by drying in various ways, the resulting kernels were always opaque, and when cut were invariably starchy in appearance. It frequently happens that wheat, the kernels of which are mature and corneous, is subjected to damp weather conditions in the field. When, finally, weather conditions permit threshing or stacking this wheat, it is



Density of a Sample of Marquis Wheat Adjusted to Various Dry-Matter Contents

The circles represent the sample containing moisture, the black spots indicate the corresponding samples after vacuum drying.

found to be "bleached," the kernels starchy, and the weight per measured bushel decreased. This is probably due to the phenomenon treated in Table IV and Figure 1.

TABLE IV

RELATION OF DENSITY OF KERNEL TO ITS MOISTURE CONTENT

The density was first determined on the moist sample, after which the same sample was dried in a vacuum oven at 100°C. and the density again determined. The calculated moisture-free density was obtained from the density on the wet basis by equation 2.

Dry matter	Density		
	Wet basis	Dry basis, experimental	Dry basis, calculated
%			
93.52	1.4264	1.4319	1.4703
91.21	1.4226	1.4257	1.4835
89.95	1.4155	1.4207	1.4852
88.65	1.4015	1.4072	1.4808
87.78	1.3989	1.4062	1.4820
86.57	1.3908	1.4010	1.4816
84.98	1.3814	1.3969	1.4824
83.28	1.3646	1.3867	1.4737
80.18	1.3469	1.3689	1.4749
79.71	1.3427	1.3717	1.4726
73.58	1.3024	1.3308	1.4633

The decrease in density is due to the formation of air spaces in the kernel after the removal of the water. This was shown by the fact that each successive weighing of the pycnometer containing the same vacuum dried wheat and toluene, after adjusting the volume, was always greater. In order to standardize this error, all weighings on such wheat were made after the wheat had been in contact with toluene for 20 minutes.

TABLE V

EFFECT ON THE APPARENT DENSITY OF KEEPING WHEAT IMMERSED IN TOLUENE

	Sample No. 97		Sample No. 99	
	Density	Dry matter	Density	Dry matter
		%		%
Original wheat air-dry	1.4264	93.52	1.4264	93.52
After increasing moisture	1.3427	79.71	1.3024	73.58
Dry basis calculated by formula 2	1.4726	100.00	1.4633	100.00
Vacuo dried Feb. 23, 1923	1.3717	100.00	1.3308	100.00
" " Feb. 26, 1923	1.3932	100.00	1.3633	100.00
" " Feb. 28, 1923	1.3955	100.00	1.3658	100.00
" " Mar. 19, 1923	1.4071	100.00	1.3827	100.00
" " July 16, 1923	1.4377	100.00	1.4264	100.00
" " Jan. 2, 1924	1.4594	100.00	1.4427	100.00
" " Mar. 1, 1925	1.4800	100.00	1.4733	100.00
" " Aug. 15, 1925	1.4933	100.00	1.4858	100.00

In order to demonstrate more clearly that this decrease in density was due to the formation of air spaces in the kernel, two of the samples of Table IV were kept immersed in toluene and the densities determined at intervals. The data are presented in Table V. It is readily seen that the apparent density increased with time of immersion in toluene, and that it even passed the density of the original wheat and the density of the dry matter as calculated from the density of the moist wheat by equation 2. The density even exceeded the density of the dry matter, as indicated by the extra-

polated line in Figure 1. The portion which was adjusted to the highest moisture content (Sample No. 99) and consequently the one which on drying had the lowest density, after more than two years still shows a lower apparent density than the portion of the same wheat which was adjusted to a slightly lower moisture content (Sample No. 97).

A distinction is usually made between bleached wheat and the yellow berry condition. According to the results of this investigation we may consider wheat bleached if it has gone through the following processes: (1) it has been reduced to a fairly low moisture content by the normal processes of ripening; (2) it has been subjected to damp conditions, rain, etc., and the kernels have taken up considerable water; and (3) this water has been removed by drying. Such a process will change dark red corneous kernels into light yellow starchy ones. The term "yellow berry" is usually restricted to the starchy condition of the wheat kernel which is sometimes found in wheat that has ripened in approximately the normal manner but the kernels of which, instead of being of the red color characteristic of the variety, are light yellow, and instead of being corneous are starchy.

It is possible that the so-called starchiness of the bleached kernels and of the yellow berry kernels is a manifestation of the same phenomenon, that is, the inability of the endosperm cells to decrease in size as the moisture is removed, thus leaving air spaces in the kernels. This ability of the kernel to decrease in size must be a property of the connective network of the endosperm, that is, the protein material. This is indicated by the fact, as previously found by other investigators, that the corneous kernels contain more protein and have a higher density than the yellow berry kernels separated from the same sample. von Feilitzen (1904), Moertlbauer (1910), Davidson and LeClerc (1917, 1918, 1923), Gericke (1920, 1922), Jardine (1922), and the extensive work of Headden (1915, 1916, 1918) have shown that nitrogen fertilizers tend to increase the protein content of wheat and to decrease the amount of yellow berry. It is possible that the proteins of different wheats may vary in their ability to contract the cells of the wheat kernels as the moisture is removed, so that two wheats with the same protein content, matured under the same meteorological and physiological conditions, might still produce the one corneous kernels and the other starchy ones. We have this condition typified in varietal differences and in the fact that some kernels from the same head of wheat may be

TABLE VI

RELATION BETWEEN MOISTURE CONTENT, METHOD OF DRYING, AND DENSITY OF KERNEL

Method of treatment	Moisture content raised to 16.72%		Moisture content raised to 19.82%		Moisture content raised to 20.29%		Moisture content raised to 26.42%	
	Density	Dry matter %	Density	Dry matter %	Density	Dry matter %	Density	Dry matter %
Original sample air dried	1.4264	93.52	1.4264	93.52	1.4264	93.52	1.4264	93.52
Original sample vacuo dried	1.4318	100.00	1.4318	100.00	1.4318	100.00	1.4318	100.00
Water added	1.3646	83.28	1.3469	80.18	1.3427	79.71	1.3024	73.58
Water added, then dried in vacuo at 100°C.	1.3867	100.00	1.3689	100.00	1.3717	100.00	1.3308	100.00
Water added, then air dried at room temperature in beakers covered with watch glasses	1.3974	92.68	1.3903	92.73	1.3860	92.42	1.3708	92.53
Water added, air dried, and finally vacuo dried	1.3988	100.00	1.3901	100.00	1.3874	100.00	1.3760	100.00

starchy and others corneous. Also, we may find both starchy parts and corneous parts in the same kernel. It is not impossible that different parts of the same kernel may be subjected to different moisture conditions during the desiccation of the kernel.

That the meteorological conditions during the ripening period have a great effect on the formation of yellow berry has been shown by several investigators. Lyon and Keyser (1905) found that by cutting the wheat at different stages of kernel development, "There is a steady increase in the amount of yellow berry as the grain becomes riper." "The amount of yellow berry increases with the lateness of ripening."

In order to see what density the wheat would have after the moisture content had been increased and then the wheat allowed to air dry, 4 aliquots of the wheat described in Table IV were allowed to air dry at room temperature in beakers covered with watch glasses. The dry-matter content of the air-dried wheat ranged from 92.42 to 92.73 per cent. The density of the air-dry wheat was less the higher the moisture content before air drying. The air-dried wheat, however, had a greater density than wheat from the same aliquot vacuum dried at once. These air-dried samples were then dried in the vacuum oven and the density was again determined, with the result that there was practically no difference between the density of the air-dried and the vacuum-dried wheat. This experiment indicates that the method of desiccation has some effect on the density of wheat.

It may be seen from the investigation thus far that the air-dry wheat kernel, if again swollen by moisture, does not have the ability to shrink to its original size on removal of the moisture by drying. It was thought that possibly different varieties of wheat might vary in their power to shrink as the moisture was removed. To investigate this point, three samples of wheat were selected. Marquis spring wheat, a strong wheat of excellent baking quality; Pacific Bluestem, a white wheat of inferior baking quality; and Kubanka, a typical durum wheat. These wheats were grown side by side in 1922 on the plots of the Montana Agricultural Experiment Station, at Bozeman.

The moisture content of aliquots of these three samples was adjusted to several levels by adding water, and after an even distribution of the moisture throughout the kernel was obtained, the density was determined. Aliquots of this moist wheat were then dried in various ways. The results are given in Table VII.

TABLE VII

DENSITY OF WHEAT AFTER DIFFERENT AMOUNTS OF WATER HAVE BEEN ADDED (COLUMNS 1 AND 2) AND DENSITY OBTAINED AFTER DEHYDRATING SUCH WHEAT IN VARIOUS WAYS

Density after adjusting the dry-matter content		Dried in loosely covered beakers, room temperature		Dried over H_2SO_4 in desiccator in ice box		Dried in vacuo over H_2SO_4 at room temperature		Wheat from columns indicated dried in vacuo at 100° and density again determined				Wheat from columns indicated ground and again dried in vacuo at 100° and the density again determined		15
1	2	3	4	5	6	7	8	9	10	11	12	13	14	Calculated to moisture-free basis from 1 & 2
Density	Dry-matter content %	Density	Dry-matter content %	Density	Dry-matter content %	Density	Dry-matter content %	Wheat from 1	Wheat from 3	Wheat from 5	Wheat from 7	Wheat from 11	Wheat from 12	
Marquis Protein, Dry Basis, 14.76%														
1.4307	92.73	1.4258	91.26	1.4343	95.62	1.4339	97.86	1.4313	1.4338	1.4324	1.4353	1.4433	1.4421	1.4812
1.4196	90.20	1.4198	91.35	1.4298	95.47	1.4280	97.71	1.4244	1.4243	1.4276	1.4295	1.4428	1.4426	1.4881
1.3950	86.38	1.4095	90.87	1.4166	95.07	1.4123	97.65	1.4046	1.4135	1.4132	1.4153	1.4396	1.4462	1.4887
1.3808	84.15	1.3986	90.98	1.4102	94.97	1.4022	97.55	1.3954	1.4004	1.4066	1.4046	1.4452	1.4451	1.4882
1.3503	80.45	1.3813	90.69	1.3931	94.84	1.3829	97.45	1.3707	1.3859	1.3887	1.3843	1.4421	1.4549	1.4776
1.3204	76.84	1.3705	90.79	1.3781	94.96	1.3726	97.48	1.3435	1.3766	1.3738	1.3732	1.4341	1.4495	1.4634
Pacific Bluestem Protein, Dry Basis, 15.61%														
1.4311	94.03	1.4236	90.31	1.4273	95.44	1.4300	99.27	1.4170	1.4111	1.4172	1.4304	1.4605	1.4605	1.4717
1.4235	91.45	1.4161	90.23	1.4199	95.18	1.4195	99.43	1.4096	1.4005	1.4111	1.4224	1.5221	1.4626	1.4828
1.3975	87.55	1.4080	89.89	1.4100	94.90	1.4074	98.99	1.3874	1.3925	1.3987	1.4120	1.4573	1.4606	1.4822
1.3896	85.44	1.3909	89.81	1.3975	94.73	1.3930	99.25	1.3834	1.3747	1.3848	1.3973	1.4528	1.4590	1.4895
1.3546	81.31	1.3756	89.71	1.3784	94.72	1.3691	99.12	1.3527	1.3584	1.3679	1.3722	1.4615	1.4626	1.4763
1.3450	80.02	1.3535	89.68	1.3678	94.61	1.3423	98.92	1.3393	1.3370	1.3558	1.3468	1.4611	1.4624	1.4733
Kubanka Protein, Dry Basis, 15.71%														
1.4276	93.29	1.4215	91.69	1.4357	95.68	1.4353	98.15	1.4314	1.4329	1.4348	1.4371	1.4535	1.4586	1.4734
1.4166	90.64	1.4213	91.74	1.4290	95.39	1.4305	98.11	1.4251	1.4312	1.4289	1.4321	1.4513	1.4590	1.4810
1.3934	87.04	1.4128	91.64	1.4223	95.20	1.4209	98.08	1.4137	1.4196	1.4218	1.4227	1.4474	1.4595	1.4811
1.3756	84.02	1.4096	91.53	1.4152	95.13	1.4155	97.98	1.4050	1.4148	1.4133	1.4185	1.4482	1.4551	1.4826
1.3524	80.77	1.3957	91.52	1.4061	94.97	1.4041	97.96	1.3872	1.4021	1.4038	1.4062	1.4516	1.4569	1.4779
1.3335	78.24	1.3901	91.49	1.3991	94.98	1.3966	97.91	1.3722	1.3971	1.3974	1.3989	1.4483	1.4540	1.4717

Table VII is divided into rather distinct parts: first, the density column (1) and the moisture-content column (2) of the wheat after adjusting the moisture content; second, the density of the dry-matter content of the wheat dried in various ways at room temperature or below; third, the density of this wheat from the various methods of drying at room temperature or below was determined after vacuum drying; fourth, the density of the wheat after grinding and vacuum drying; and fifth, the density of the dry matter calculated by equation 2 from the data of columns 1 and 2. The wheat air dried in beakers covered with watch glasses had a density as indicated in column 3, when its moisture content was that given in column 4. Aliquots dried over sulphuric acid in a desiccator placed in an icebox gave the values of columns 5 and 6. As the desiccator stood in the icebox for approximately three months, the wheat was probably pretty nearly in moisture equilibrium with the sulphuric acid. In order to try the effect of fairly rapid drying at room temperature, samples of the wheat were dried over sulphuric acid in a vacuum desiccator at room temperature. The results are given in columns 7 and 8. The third part of this experiment was to dry the samples of columns 1, 3, 5, and 7 in the vacuum oven and again determine their density. The corresponding values are given in columns 9, 10, 11, and 12. The fourth part of this experiment was to grind the samples from columns 11 and 12 in a coffee mill, dry them in the vacuum oven, and determine the density of the ground moisture-free material, given in columns 13 and 14.

By plotting the densities, column 1, of the wheat as abscissa against the dry matter content as ordinate, it was found that the points fell approximately on straight lines. Extrapolating these lines to 100 per cent dry matter content indicated a density of 1.488 for Marquis, 1.483 for Pacific Bluestem, and 1.477 for Kubanka. These values should be compared with the calculated values in column 15. The line for the Pacific Bluestem lies slightly above that for Marquis and at approximately the same angle, while the line for Kubanka lies above Marquis and at a slightly greater angle with the axis of density. This means that at a given moisture content the density of the Marquis wheat is slightly greater than that of the other two wheats.

If we examine the effect of air drying by comparing columns 1 and 3, it is apparent that for the various moisture contents Kubanka increased most in density on the removal of water, Marquis next, and Pacific Bluestem least. By comparing columns 3 and

9 it is seen that the wheat of the higher moisture content, dried at once when placed in the vacuum oven at 100° C., altho containing no moisture, was less dense than the air-dried wheat. It seems that less contraction of the kernel structures occurred in rapid drying at a high temperature than when the kernel was dried at a slower rate at lower temperatures. This is borne out by the experiment in which the wheat was dried over sulphuric acid in the icebox, altho in this case the moisture content was also lower. It was observed that if the wheat contained about 8 per cent of moisture or less, subsequent drying in the vacuum oven did not change the density appreciably for Marquis and Kubanka, while Pacific Bluestem showed a slight lowering. This is indicated by comparing columns 5 and 11. When the wheat is ground and the density determined on the vacuum dried ground material—columns 13 and 14—the effect of the moisture content is apparently eliminated by the grinding and the densities are higher than any of the other experimental values. They do not, however, reach the calculated value, column 15. This may be taken to indicate that this ground material still contained air spaces. It was thought that the results in Table VII indicated that Pacific Bluestem wheat was less able to contract on the removal of water than were Kubanka and Marquis, that is, the structure of the latter two wheats exhibited what might be called a greater cohesive force, or their connecting net work structure was more elastic.

This difference in ability of the various wheats to contract on the removal of moisture was so interesting that the experiment was repeated with other samples of Marquis, Pacific Bluestem, and Kubanka wheat. The data are presented in Table VIII. This table is self-explanatory if considered in the light of the discussion of Table VII. Plotting columns 1 and 2 gave straight lines which on extrapolation indicated a density of the dry matter of the Marquis wheat of 1.467, of the Pacific Bluestem of 1.473, and of the Kubanka of 1.471. Table VIII, considered as a whole, confirms the main point brought out in Table VII. A comparison of columns 1 and 7, of Table VIII, brings out the differences in the three wheats. The sample of Pacific Bluestem showed the least ability to contract on the removal of the moisture by drying in the vacuum oven at 100° C., and the density of the vacuum dry samples was much less than that of the same samples containing moisture. This was especially true with the sample containing the greatest amount of moisture. This sample of Marquis wheat did not contract as much as did the sample used in Table VII; in fact, the density of

TABLE VIII

DENSITY OF WHEAT AFTER THE ADDITION OF VARIOUS AMOUNTS OF WATER (COLUMNS 1 AND 2) AND DENSITY OBTAINED AFTER DEHYDRATING THIS WHEAT IN VARIOUS WAYS

Density after adjusting dry matter content		Dried in watch glasses at room temperature		Kept in desiccator over H_2SO_4 in icebox		Wheat from columns indicated dried in vacuo at 100°C. and density again determined			Calculated to moisture-free basis from 1 and 2
1 Density	2 Dry matter %	3 Density	4 Dry matter %	5 Density	6 Dry matter %	7 Wheat from 1	8 Wheat from 3	9 Wheat from 5	10
				Marquis					
1.4130	92.49	1.4105	92.52	1.4004	89.14	1.4071	1.4104	1.4074	1.4625
1.3856	86.81	1.3985	92.13	1.3882	88.39	1.3825	1.3939	1.3898	1.4729
1.3593	82.33	1.3923	92.22	1.3777	87.46	1.3528	1.3828	1.3781	1.4743
1.3435	78.64	1.3821	92.05	1.3806	88.70	1.3096	1.3748	1.3750	1.4836
1.3137	75.18	1.3816	92.16	1.3744	88.45	1.2723	1.3757	1.3827	1.4677
				Pacific Bluestem					
1.3936	88.10	1.3764	91.49	1.3880	88.30	1.3817	1.3953	1.3861	1.4654
1.3594	82.87	1.3605	91.92	1.3741	87.61	1.3426	1.3779	1.3720	1.4699
1.3304	78.75	1.3404	91.98	1.3623	87.58	1.2828	1.3580	1.3567	1.4623
1.3063	75.07	1.3263	92.14	1.3462	87.53	1.2046	1.3408	1.3383	1.4564
1.2801	72.49	1.3179	92.12	1.3416	88.78	1.1439	1.3343	1.3354	1.4348
				Kubanka					
1.4122	90.48	1.4181	92.96	1.4057	89.44	1.4210	1.3947	1.4220	1.4531
1.3773	84.71	1.4052	92.93	1.3925	89.06	1.3983	1.3701	1.4168	1.4791
1.3515	80.83	1.3970	92.82	1.3860	89.01	1.3557	1.3644	1.3980	1.4760
1.3355	77.22	1.3970	92.88	1.3859	89.38	1.3128	1.3629	1.3969	1.4841
1.3033	72.31	1.3944	92.86	1.3850	90.34	1.3226	1.3589	1.3954	1.4771

the vacuum dry wheat was less than that of the wheat containing water. Comparing the aliquots which were dried at once in the vacuum oven with those which were first partially dried by slower methods at lower temperatures, shows that the latter had the greater density.

Samples of Marquis, Pacific Bluestem, and Kubanka wheat were increased in moisture content, then divided into aliquots and placed in a vacuum oven at 100° C. At intervals an aliquot of each wheat was removed and the density determined; the aliquot was then returned to the oven and the drying completed. The data obtained are given in Table IX. It will be observed that here also Pacific Bluestem showed less ability to shrink on the removal of the moisture than did Marquis and Kubanka. Marquis and Kubanka did not increase in density on the removal of the water as much as would be expected from Tables VII and VIII. But the difference in behavior of these two wheats when compared with the Pacific Bluestem is sufficiently marked to confirm the results of Tables VII and VIII, that Pacific Bluestem has less ability to contract on the removal of the water.

TABLE IX

RATE OF DRYING IN VACUUM OVEN AT 100°C. AND ITS EFFECT ON THE DENSITY, ALSO DENSITY ON SUBSEQUENTLY DRYING THE SAMPLE IN VACUUM OVEN FOR 18 HOURS

Time of drying	Dry matter	Density	Density after complete drying	Calculated to a moisture-free basis
hrs.	%			
		Marquis		
0	76.72	1.3228	1.3311	1.4683
¼	81.17	1.3377	1.3519	1.4529
½	86.39	1.3433	1.3403	1.4210
1	90.89	1.3502	1.3385	1.3999
2	95.36	1.3453	1.3314	1.3685
4	96.82	1.3453	1.3359	1.3609
18	100.16	1.3302	1.3322	1.3302
		Pacific Bluestem		
0	75.99	1.3048	1.2536	1.4458
¼	79.71	1.3062	1.2591	1.4181
½	85.03	1.2874	1 2691	1.3569
1	89.82	1.2760	1.2499	1.3178
2	94.41	1.2805	1.2586	1.3024
4	96.11	1.2803	1.2619	1.2951
18	99.78	1.2534	1.2529	1.2540
		Kubanka		
0	77.24	1.3315	1.3387	1.4774
¼	.....	1.3436	.....	.....
½	85.28	1.3531	1.3486	1.4420
1	89.86	1.3590	1.3442	1.4170
2	94.65	1.3620	1.3488	1.3908
4	96.22	1.3664	1.3543	1.3865
18	99.84	1.3426	1.3428	1.3433

As the Pacific Bluestem wheat used in these experiments showed inferior baking qualities when compared with Marquis, it was thought that perhaps starchy kernels might show less ability to contract on drying than corneous kernels separated from the same sample of wheat. This hypothesis was tested by selecting several samples of wheat which contained both yellow berry and corneous kernels. These samples were separated into completely corneous and completely yellow berry kernels. The density of the air-dry kernels was determined and aliquots were treated in various ways and the density was again determined. The protein content of the various fractions was also determined. The values obtained with three samples are given in Table X. Column 3 shows that the corneous kernels have a greater density than do the yellow berry kernels. This difference seems to persist throughout the various treatments, explained in the table headings. The total protein content more or less parallels the density of the kernels, the more dense kernels containing the most protein.

The results given in Table X show that on adding water to corneous and yellow berry kernels separated from the same sample, both decrease in density, but the corneous kernels decrease most. Evidently both corneous and yellow berry kernels are approaching the same density as water is added. This may be easily understood when we consider that the corneous kernels had a considerably higher density to start with, while the yellow berry kernels contained air spaces which could be filled with water, thus tending to counteract the effect of the water in decreasing the density. As this water is subsequently removed, the kernels which were originally corneous contract more than those which were originally yellow berry.

The supposition that the corneous kernels would contract more than the yellow berry kernels was confirmed, altho not to the extent expected. If the comparison is made on the basis of the densities in columns 5 and 7, the corneous kernels in Kanred sample No. 1 contracted 0.0111 units of density more than the yellow berry kernels; those in Kanred sample No. 2 contracted 0.0075 units more; and those in Marquis sample No. 1, 0.0145 units more. If the comparison is made on the basis of columns 5 and 9 the values are 0.0103, 0.0046, and 0.0177 respectively. The grinding seems to do away with the differences in density, as shown by column 10.

TABLE X

RELATION OF YELLOW BERRY TO DENSITY AND PROTEIN CONTENT OF THE WHEAT KERNEL

1 Lab. No.	Description of separations 2	Original air-dried sample		Material from 3 after increasing moisture content		Material from 5 air dried		Material from 7 vacuum dried	Material from 9 ground and vacuum dried	Protein, dry basis, %
		3 Density	4 Dry matter %	5 Density	6 Dry matter %	7 Density	8 Dry matter %	9	10	11
Kanred	Corneous	1.4464	94.17	1.2978	71.41	1.3737	93.16	1.3737	1.4376	12.47
No. 1	Yellow	1.4196	93.90	1.2856	71.27	1.3504	92.97	1.3512	1.4391	10.30
	Orig. sample 15.6% yellow	1.4346								11.37
Kanred	Corneous	1.4423	94.34	1.3044	71.62	1.3811	92.99	1.3781	1.4382	11.62
No. 2	Yellow	1.4078	93.75	1.2922	70.87	1.3614	92.78	1.3613	1.4482	9.91
	Orig. sample 77% yellow	1.4125								10.18
Marquis	Corneous	1.4326	90.69	1.3036	73.04	1.3763	89.77	1.3751	1.4369	15.16
No. 1	Spotted	1.4292	90.35	1.2983	72.82	1.3733	89.70	1.3729		14.34
	Yellow	1.4051	90.59	1.2754	72.85	1.3336	89.64	1.3292	1.4255	11.12

TABLE XI

RELATION OF YELLOW BERRY TO DENSITY AND PROTEIN CONTENT OF THE WHEAT KERNEL

Lab. No.	Description of separations		Original air-dry sample		Material from 3 after increasing moisture content		Material from 5 vacuum dried	Crude protein dry basis Nx5.7
1	2		3 Density	4 Dry matter	5 Density	6 Dry matter	7 Density	8
				%		%		
Kanred	Corneous	11.36%	1.4438	90.72	1.3036	73.04	1.2958	12.12
No. 3	Mixed	45.31	1.4350	90.67	1.2983	72.82	1.2808	11.17
	Yellow	43.34	1.4108	90.59	1.2754	72.85	1.2600	9.84
Kanred	Corneous	28.4	1.4281	91.15	1.2915	73.27	1.2976	13.71
No. 4	Mixed	47.7	1.4070	90.75	1.2822	73.04	1.2877	11.96
	Yellow	23.9	1.3792	90.80	1.2763	73.08	1.2805	10.80
Kanred	Corneous	13.31	1.4324	90.71	1.2938	73.19	1.3089	13.25
No. 5	Mixed	40.13	1.4195	90.82	1.2892	73.58	1.3028	12.04
	Yellow	46.55	1.3961	90.78	1.2763	73.16	1.2812	10.61
Marquis	Corneous		1.4300	92.13	1.2895	70.60	1.2980	15.61
No. 2	Yellow		1.4099	91.93	1.2751	70.80	1.2584	11.93
	Original sample		1.4264	93.52				
Marquis	Corneous		1.4315	91.65	*		1.4344	14.80
No. 3	Yellow		1.4005	91.05			1.3986	11.10
Kanred	Corneous		1.4303	90.99	*		1.4357	12.99
No. 6	Yellow		1.3817	90.51			1.3852	10.70

*Vacuum dried direct.

The relation of corneous and yellow berry kernels to shrinkage was further investigated and some of the results obtained are given in Table XI. By a comparison of columns 5 and 7 the corneous kernels are shown to contract more than the yellow berry kernels by the following density units: Kanred No. 3, 0.0076; Kanred No. 4, 0.0019; Kanred No. 5, 0.0102; and Marquis No. 2, 0.0252. The moisture was removed from two air-dry samples—Marquis No. 3 and Kanred No. 6. The density of the vacuum dried material was nearly the same as of the air-dry kernels. The contraction was only slightly in favor of the corneous kernels, the values being 0.0048 and 0.0019, respectively. Tables X and XI both show the other difference, already mentioned, between the corneous kernels and the yellow berry kernels, that is, the corneous kernels decrease more in density on the addition of moisture than do the yellow berry kernels. The values of this difference for the various samples are given in Table XII, taking these samples in the order in which they occur in the two tables. Table XII indicates that the corneous kernels decrease more in density on increasing the moisture content and increase in density more on decreasing the moisture content than do the starchy kernels.

Determinations similar to those given in Tables X, XI, and XII were made on the separations of corneous and yellow berry from six other samples of wheat, but owing to a mistake they were not adjusted to near enough the same moisture content and therefore the results will not be presented.

TABLE XII

DIFFERENCE IN DENSITY UNITS BETWEEN CORNEOUS AND YELLOW BERRY KERNELS

The corneous kernels decrease in density more on the addition of water, as indicated by column 2 while they also contract more on its removal, as indicated by column 3.

	Excess decrease in density	Excess increase in density
Kanred No. 1	0.0146	0.0111
Kanred No. 2	0.0223	0.0075
Marquis No. 1	—0.0007	0.0145
Kanred No. 3	0.0048	0.0076
Kanred No. 4	0.0337	0.0019
Kanred No. 5	0.0188	0.0102
Marquis No. 2	0.0057	0.0252

In order to investigate the effect of different methods of desiccation on the developing kernel, that is, on wheat that has never been brought to an air-dry condition, a considerable portion of immature wheat was threshed by hand and the wheat was divided into 10-gram aliquots and duplicate aliquots were dried in the various ways. The data are given in Table XIII. The wheat as threshed contained a little less than 50 per cent of moisture. The

wheat was desiccated by the method indicated until the aliquots contained about 7 per cent of moisture. The weight of each aliquot when vacuum dried for the determination of the vacuum dry density is given in the first column of figures in Table XIII. The fluctuation in these values is perhaps due to errors in sampling and perhaps to some variation in the loss of dry matter by respiration. With the exception of the aliquots which were dried in the dark in covered beakers, all methods of desiccation produced wheat of essentially the same density. An experiment of this kind carried out on developing kernels of about 30 per cent moisture content would be more likely to show whether or not differences in the density of the wheat kernel could be produced by different methods of desiccation.

TABLE XIII

EFFECT ON DENSITY OF VARIOUS METHODS OF DRYING IMMATURE WHEAT

Ten-gram aliquots of the freshly threshed wheat were desiccated in duplicate by the procedures indicated.

	Vacuum dry weight	Dry matter content after partially drying	Density after partially drying	Density after vacuum drying
	grams	%		
Sunlight in lipped beakers covered	5.083	93.69	1.4279	1.4275
with watch glasses	5.092	93.70	1.4246	1.4261
Dark in lipped beakers covered	5.010	92.99	1.4155	1.4193
with watch glasses	5.014	93.58	1.4143	1.4099
Watch glass in	5.070	93.16	1.4306	1.4293
light	5.091	92.91	1.4284	1.4264
Watch glass over	5.082	93.41	1.4265	1.4232
H_2SO_4	5.007	91.80	1.4276	1.4420
Watch glass over	5.034	93.43	1.4276	1.4229
$CaCl_2$	4.967	93.09	1.4261	1.4244
Watch glass with	5.109	93.72	1.4247	1.4201
fan and air 30°C.	5.106	93.69	1.4304	1.4307

In order to see how different samples of wheat of the same variety differed in density and in their ability to contract on the removal of moisture, 26 samples of Marquis spring wheat were subjected to investigation. These samples were the ones submitted to the Montana State Fair in competition for the prize for Marquis wheat. In order to get a rough idea of the correlation between the various factors, the 26 samples were arranged in four different orders: (1) increasing loaf volume, (2) increasing crude protein content, (3) increasing density of the air-dry wheat, and (4) increasing weight per kernel. The average of the 13 lowest was then compared with the average of the 13 highest. The density of the 26 samples was determined after fourteen different treat-

ments designed to bring out the effect of moisture history on the density, and the attempt was made to correlate these density determinations with the four variables listed above. Table XIV gives a summary of part of these data; the other data were found to add nothing to those given. These wheats were unwisely chosen for such a study because they all showed nearly the same baking value. Thus, the average of the 13 lowest in loaf value differs from the 13 highest by only 136 cc. One of the factors which stood out most clearly was that if the wheat originally had a relatively high density, this was maintained throughout the whole series of treatments. There is apparently a slight correlation between high density and low moisture content. The density of the original wheat is not related to the protein content of the wheat in this series. A positive correlation between weight per kernel and weight per bushel is indicated.

Discussion

The data in Tables I, II, and III bring out very clearly that wheat which has a low weight per bushel may not necessarily be light wheat so far as its actual density is concerned. The weight per bushel depends on two factors: (1) the actual density of the wheat and (2) the fractional part of the volumetric measure actually occupied by wheat. Thus, when light or heavy wheat is mentioned it should be made clear whether weight per bushel or density is under consideration.

This work confirms the findings of other investigators that the air-dry kernel may contain air spaces and that the proportional volume of the air spaces in the kernel is one of the factors which determine the density of the kernel as a whole.

It should be remembered that the freezing conditions to which the frozen samples of Table III were subjected were more severe than any which they would encounter in the field. This low temperature was chosen in order to eliminate by one experiment as many factors as possible which might be affected by freezing. If this severe freezing did not affect a given property of the wheat, then one should be reasonably sure that less severe freezing conditions would not do so. The freezing experiments reported were also planned to eliminate as many of the variables as possible, so that a comparison could be made of samples of frozen and nonfrozen wheat at the same stage of maturity subjected to as nearly the same conditions as possible except for the freezing. Studies carried out on wheat subjected to actual freezing conditions in the field have been very inconclusive because of the large number of variable factors operating.

TABLE XIV

RELATION OF DENSITY TO OTHER FACTORS OF VARIOUS SAMPLES OF MARQUIS WHEAT OF HIGH QUALITY

Av. of 13 samples	Loaf volume	Texture	Absorption	Wt. per bu.	Wt. per kernel	Crude protein, dry basis (Nx5.7)	Moisture content of air-dry wheat	Density of air-dry wheat	Density of vacuum dried wheat	Density of dry matter, calculated
	cc.	%	%	lbs.	mgm.	%	%			
Data arranged in order of increasing loaf volume.										
Lowest	2009	92.1	59.3	62.6	30.1	15.04	8.75	1.4146	1.4208	1.4738
Highest	2145	95.7	58.8	62.5	31.2	15.63	9.24	1.4107	1.4174	1.4728
Data arranged in order of increasing crude protein content.										
Lowest	2059	93.3	58.9	62.4	30.2	14.12	9.12	1.4124	1.4189	1.4740
Highest	2095	94.5	59.2	62.7	31.1	16.55	8.87	1.4129	1.4193	1.4726
Data arranged in order of increasing density of the original air dry wheat.										
Lowest	2095	95.1	58.8	62.4	31.4	15.59	9.53	1.4037	1.4108	1.4667
Highest	2059	92.7	59.3	62.7	29.9	15.08	8.46	1.4216	1.4274	1.4799
Data arranged in order of increasing weight per kernel.										
Lowest	2077	93.1	58.9	62.1	28.3	15.30	8.92	1.4140	1.4195	1.4743
Highest	2077	94.7	59.2	63.0	33.0	15.37	9.07	1.4113	1.4187	1.4723

The experiments on the series of samples which were severely frozen, Table III, indicate that at the immature stages of kernel development, frozen samples had a higher density than had samples collected at the same stage of maturity which were not frozen. The most immature frozen samples were unable to contract further, however, on vacuum drying, hence the experimental value obtained for the density of the vacuum dried wheat is much less than that of the air-dried wheat. If we consider sample S-132F, and calculate the density the vacuum dried wheat should have if the 9.39 per cent of moisture which the air-dried kernel contained was removed, without the kernel decreasing in size, we obtain the value 1.2897. This calculated value is in pretty fair agreement with the experimental value 1.2864, indicating that the immature frozen wheat lacked the ability to decrease in size as this last 9.39 per cent of moisture was removed by the vacuum oven. This result might be interpreted to indicate that the severe freezing of the very immature wheat had affected the protein quality or prevented the synthesis of the protein which could cause the kernel to contract as the moisture was removed. These immature frozen samples behaved like Pacific Bluestem wheat in their failure to contract on the removal of moisture. The density of the lightly frosted wheat (Tables I and II) showed no marked effect of the freezing.

Most investigators of the density of wheat have disregarded its moisture content. The work presented here indicates that it may be the most important factor in determining the density of wheat and that density comparisons made without a consideration of the previous moisture history of the kernel may be of doubtful value. We know of no accurate method of correcting for the moisture factor. It is doubtful whether it is safe to assume that normal air-dried wheats from various sources all have nearly enough the same moisture content and moisture history to justify direct comparisons. It is believed that the main factors which determine the density of wheat are (1) moisture content and moisture history, (2) amount of protein, (3) kind of protein. In selected extremes there is probably a relation between the protein content and the density which might be great enough to over-shadow slight effects of moisture history and protein quality. Such a case might be the comparison of the protein content and density of samples containing a high percentage of yellow berry kernels with samples containing a high percentage of corneous kernels. An apparent relationship between protein content and density can best be shown by a separation of corneous kernels and yellow berry kernels from the same sample.

If we restrict ourselves to samples of wheat all of which are corneous, or to samples all of which are starchy but grown under different conditions, and try to establish a close relationship simply between density and protein content without regard to the other two factors, we are doomed to failure.

These experiments do not preclude the possibility that the starch grains play a rôle in the density and density changes in wheat. The work of Cobb (1904) and Lyon and Keyser (1905) might be interpreted as pointing to such a possibility, while the experiments of Roberts (1919) would not. Since Nowacki (1870) and Wollny (1886) found the air spaces in the protein network of the endosperm, it seems more reasonable, in the light of our present knowledge, to explain the density effects reported in this paper as due mainly to the protein phase.

If it is true that the density of wheat is regulated by the three factors mentioned, then possibly by suitable experiments or calculations involving changes in the moisture content of the wheat with the corresponding changes in density, one might bring the protein quantity and quality into prominence. Thus far this object has been accomplished in only two cases, (1) the comparison between two Marquis and Pacific Bluestem wheats, (2) by showing the effect of severe freezing on very immature wheat.

Differences in the change in density between corneous and yellow berry kernels separated from the same sample when subjected to a change in moisture content agree with the idea that wheat containing more protein is able to contract more on removal of moisture than is wheat containing less protein. This is not the only explanation, however. As Table XII indicates, the corneous and yellow berry kernels both decrease in density on increasing the moisture content, the corneous kernels decreasing in density the most. When the process is reversed the corneous kernels also contract the most. The reason why the yellow berry kernels do not decrease in density on increasing the moisture content as rapidly as do the corneous kernels, may be a tendency for the water to fill the air spaces in the yellow berry kernel rather than expand it. If this explanation is accepted, then doubt is thrown on this experiment as showing differences in either protein quantity or quality between corneous and yellow berry kernels separated from the same sample. Durum wheats, on the other hand, are usually characterized by corneous kernels, so that if this property of being able to contract on the removal of water is related to the corneousness of the kernels, then Durum wheats should show this behavior. This was actually found to be the case with the two samples of Kubanka investigated. These two samples

were able to contract more on removal of moisture than were the samples of corneous Marquis wheat.

So far, experiments have failed to show a relation between protein quantity and quality and the ability of the kernel to contract on the removal of moisture when the study was carried out on wheats all of which were corneous and all of the same variety. This may be due to one of two causes, either this ability of the kernel to decrease in size is the same for all corneous kernels or the samples investigated were too nearly of the same quality to show distinct differences. It is believed that the latter explanation is the most probable one.

The inability of wheat which has been desiccated in the field to a corneous condition and subsequently subjected to damp weather conditions, to decrease again to its original volume on the removal of the water, results in starchy kernels and produces wheat which is called "bleached."

Conclusions

1. The density of wheat grown under uniform conditions and harvested at various stages of maturity does not differ to any great extent provided it is desiccated under approximately uniform conditions and is not affected by different amounts of yellow berry or by great differences in protein content.

2. Light freezing in itself does not affect the density of wheat to any marked degree, while severe freezing, at the immature stages as carried out in the experiments reported here, causes an increase in density.

3. The moisture content and moisture history exert a marked effect upon the density of wheat.

4. An explanation is offered for the effect of damp weather on wheat which has once been desiccated in the field, in producing the so-called "bleached wheat."

5. It was shown that different samples of wheat may show marked differences in the ability of the kernels to contract on the removal of moisture from wheat which has once been air dried and then increased in moisture content.

6. It is suggested that three factors affect the density of wheat other than the possibility of kernel size: (1) moisture content and moisture history, (2) protein content, and (3) protein quality.

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A DETERMINATION OF IRON, CALCIUM, MAGNESIUM, PHOSPHORUS, ASH, AND PROTEIN IN HARD SPRING WHEAT AND IN THE FLOUR STREAMS REPRESENTING THE LARGEST VOLUME OF FLOUR PRODUCED IN ITS MILLING

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The chief purpose of this research was to determine the quantity of iron in some of the principal mill streams and to ascertain, if possible, whether or not any relationship or correlation exists between the various elements and components as found in these streams. The mill streams used were obtained from a five-break mill producing twelve middlings streams. The mill is located in Minneapolis, Minn., and the wheat milled was northwestern hard spring of the Marquis variety grown in the state of North Dakota. These streams were taken in 1913 with the original purpose of making a different use of the analytical data from that to which it has been subjected. With the close of the war, the investigational work was discontinued, but a recent survey of the work suggested that some of the analytical data, besides being of scientific value, might have a bearing upon the relative nutritional value of the different flour streams and consequently upon the flours made from these streams.

Iron exists in wheat in very small quantities, and it is considered by the foremost investigators of milled cereal products to be in organic combination, and in such a form as to enter readily into the metabolic and assimilative processes of the body. It may also be associated with enzymic action of flours. Calcium, magnesium, and phosphorus are the chief mineral constituents composing the bony structures of the body, and calcium and phosphorus metabolism may be associated with the occurrence of rickets. The relative quantities of these elements in the intermediate streams formed in the milling process should vary, depending upon the relative quantities of the different wheat kernel structures composing the different streams. Such considerations suggested that a determination, distribution, and possible correlation of the various inorganic elements and components determined might be of nutritional as well as scientific value.

The review of literature made did not show that iron, calcium, and magnesium had previously been determined in the various mill streams. Iron was determined in bran, germ, and flour by McHargue (1924) and by Dempwolf (1869) in wheat and wheat flours. Ash, phosphorus, and protein have previously been determined in mill streams by Swanson, Willard, and Fitz (1915) and B. R. Jacobs (1915), of the United States Department of Agriculture, Bureau of Chemistry. No attempt has been made to correlate these values in the different mill streams.

Bailey (1925) showed from Dempwolf's data that the percentage of magnesium oxide in the ash of flours decreased in proceeding from the lower grade to the higher grade flours, while that of calcium oxide increased. He showed that the ratio $\frac{CaO}{MgO}$ varied from 1.15 in high-grade flours to 0.37 in the lower grade flours. Similar ratios of calcium oxide and magnesium oxide in the ash of wheat flours were shown by Teller (1896) and also by Grossfeld (1920). The latter found the ash of fine flour to contain calcium and magnesium in about equal proportions, while the ash of the lower grade flours contained about half as much calcium as magnesium.

Experimental

Methods

Moisture.—Moisture was determined in order to reduce the analytical results to the dry-flour basis for the purpose of comparison. Samples weighing 2.5 grams were heated in petri dishes at a temperature of 100° C. for three hours in an automatically controlled electric air drying oven.

Ash.—Ash was determined by igniting 2.5-gram samples in an automatically controlled electric muffle furnace at 600° C. ±20° until a constant weight was reached.

Iron.—The iron was determined by a modification of the method of Lachs and Freidenthal (1911). This is a colorimetric method and is based upon the formation of iron sulfo-cyanate $Fe(CNS)_3$ which in the non-ionized condition is colored red.

The ash from a 1.5-gram sample was dissolved in 1 cc. of 6N HCl and 1 cc. H_2O, then transferred to a graduated test tube with 6-7 cc. water and the volume made up to 10 cc.

A standard solution of iron was prepared by dissolving 0.0100 gram of chemically pure iron wire in the smallest quantity of 6N HCl necessary to dissolve it. The iron was oxidized with a few

drops of H_2O_2 to the ferric form and made up to a volume of 1000 cc. This solution contained 0.00001 grams of Fe per cc. Definite quantities of this solution were used as standards. One cc. of 6N HCl was added to each standard and the volume made up to 10 cc., or to a volume equal to that of the sample. To each of the standards and to the sample, 5 cc. of 50% iron-free KCNS solution were added, and the color intensities were matched directly without extracting the $Fe(CNS)_3$ with ether as in the original Lach-Friedenthal procedure. The excess CNS ions have the same effect upon the retardation of ionization as the ether, and as only a small quantity of $Fe(CNS)_3$ is present in solution at any time, the large excess of KCNS retards the ionization to such an extent that only a negligible quantity will be in the ionized condition and the maximum intensity will thus be obtained.

Errors arising from minute quantities of iron in the reagents were obviated by using the same volumes of reagents in both standard and sample solutions.

This method gives good results if the sample is completely ashed, but unburned carbon and other suspensions cause difficulties by giving the solution a different shade of color from that produced by the standard.

Phosphorus.—The phosphorus was determined by both gravimetric and volumetric methods. The flour was oxidized in the wet way and the phosphorus precipitated as a phosphomolybdate and weighed, then dissolved in nitric acid and titrated with a standard alkali. The two methods gave results which checked within experimental error in almost every case. In the instance when the results did not check, the values obtained by the titration method were used.

Crude protein.—Crude protein was determined by the Arnold-Gunning modification of the Kjeldahl method. The factor 5.7 was used for converting the percentage of nitrogen to crude protein.

Calcium and magnesium.—Calcium and magnesium were determined by the method used by McCrudden (1910) in determining calcium and magnesium in the presence of phosphates and small quantities of iron, devised especially for the analysis of foods, urine, and feces. The fat and carbohydrate content of the individual streams were also determined, but the results are not reported.

Discussion

Ash.—The average percentage of ash, as shown in Table I, is higher in the break streams than in the middlings streams. It is higher in the wheat and highest of all in the bran. It increases in the break streams (except the second) with the number of the stream, and in the middlings streams (except the second) with the number of the stream. In straight flour it is higher than the average in the middlings streams and lower than the average in the break streams. In clear flour it is lower than the average in the break stream and higher than the average in the middlings streams. In the analyses of Swanson, Willard, and Fitz, (1915) and in those of Jacobs (1915) where a large number of middlings streams were used, the ash in the straight flour is lower than the average in the middlings streams.

Mayer (1857) found that the ash content of flours diminished with the increase in refinement. Altho the ash content has been used extensively as a criterion of flour grade, Bailey (1925), in his monograph, "The Chemistry of Wheat Flours," says that the inorganic ingredients of the ash of the flour are not of themselves directly responsible for the properties of the flour with which the percentage of ash is correlated, and that the ash content is of significance because it is correlated with the flour properties in question rather than because it is directly responsible for these properties.

Iron.—The percentage of iron, as shown in Table I, is higher in the break streams than in the middlings streams. It is higher in the wheat and highest of all in the bran. It increases (except in the second break) with the number of the break stream and increases also in the middlings streams with the number of the stream. In straight flour it is lower than the average of the break streams and higher than the average of the middlings streams. In clear flour it is lower than the average of the break streams and higher than the average of the middlings streams.

In the ash from the middlings streams the iron increases with the number of the stream. In the ash from the break streams, it shows no regular increase or decrease with the number of the stream. In the ash of straight flour, it approaches the percentage of iron in the ash of the average middlings streams; while in clear flour it approaches the concentration of iron in the ash of the average break streams. In the ash of the wheat, it equals the iron in the ash of the average break and middlings streams; while in the ash and bran, it equals the iron in the ash of the average break streams. The percentage of iron is lower in the ash of the bran than in the ash of the average break streams.

Dempwolf (1869) reported the percentage of Fe_2O_3 in a number of milled products. These percentages, translated in terms of iron percentages, average more than three times the quantity of iron found by the authors. McHargue (1924) found 210 parts per million, or 0.021%, iron in bran; 270 parts per million, or 0.027%, in germ; and 24 parts per million, or 0.0024%, in flour. These percentages are many times greater than those found by the authors of this paper. As Dempwolf found 0.145% iron in the ash of bran (Kleien) and a much higher percentage (0.443%) in the ash of the finest flour (Auszugmehl), it is presumed that the higher percentages obtained by Dempwolf might be due to the method used in determining the iron.

Calcium.—The calcium, as shown in Table I, averages higher in the flour of the break streams than in the flour of the middlings streams. It is lower in the straight flour than in the clear flour It is lower in the straight flour than in the average of either the break or the middlings streams and higher in the clear flour than in the average of either the break or the middlings streams. It is higher in the wheat and highest of all in the bran.

TABLE I

COMPOSITION OF WHEAT, AND MILL STREAMS

	Percentages in flour streams on oven-dried basis					
	Ash	Fe	Ca	Mg	P	Crude protein (Nx5.7)
First break	0.683	0.00079	0.0184	0.0545	0.168	14.73
Second break	.668	.00069	.0121	.0493	.158	13.70
Third break	.841	.00099	.0177	.0688	.198	16.95
Fourth break	1.344	.00151	.0250	.1158	.321	18.80
First middlings	.418	.00035	.0165	.0222	.091	11.73
Second middlings	.396	.00037	.0100	.0219	.097	11.47
Third middlings	.416	.00041	.0164	.0243	.109	11.71
Fourth middlings	.448	.00047	.0099	.0276	.115	12.10
Straight flour	.512	.00050	.0114	.0318	.132	12.54
Clear flour	.810	.00088	.0275	.0613	.197	14.52
Wheat	1.761	.00184	.0317	.1543	.384	14.17
Bran	4.868	0.00550	0.0965	0.4505	1.134	15.16

As shown in Table II, the calcium averages lower in the ash of the break streams than in the ash of the middlings streams. It is still lower in the ash of bran and lowest of all in the ash of wheat. With the exception of the second break, it decreases with the number of the break stream and with the exception of the second middlings stream, it decreases with the number of the middlings stream. It is lower in the straight flour than the average

in either the break streams or the middlings streams. It is higher in the clear flour than the average in either the break streams or the middlings streams. The calcium is a little higher in the ash of the straight flour than in the ash of the average break streams.

TABLE II

PERCENTAGES OF IRON, CALCIUM, MAGNESIUM, AND PHOSPHORUS IN THE ASH OF WHEAT AND MILL PRODUCTS

	Fe	Ca	Mg	P	P_2O_5
First break	0.116	2.694	7.980	24.60	56.33
Second break	.103	1.811	7.380	23.65	54.16
Third break	.118	2.105	8.181	23.54	53.91
Fourth break	.112	1.860	8.616	23.89	54.91
First middlings	.086	3.947	5.311	21.77	49.85
Second middlings	.093	2.523	5.530	24.49	56.03
Third middlings	.099	3.942	5.841	26.20	60.00
Fourth middlings	.105	2.210	6.161	25.67	58.78
Straight flour	.098	2.226	6.211	25.78	59.03
Clear flour	.109	3.040	7.568	24.32	55.69
Wheat	.105	1.800	8.762	21.80	49.92
Bran	0.113	1.982	9.254	23.30	53.36

Magnesium.—Magnesium averages higher in the break streams than in the middlings streams. It is still higher in the wheat and highest of all in the bran. With the exception of the second break stream, it increases with the number of the break stream; and in the middlings stream it increases with the number of the middlings stream. It is lower in the straight flour than the average in the break streams and higher than the average in the middlings streams. It is lower in the clear flour than the average in the break streams and higher than the average in the middlings streams.

Phosphorus.—The phosphorus averages a little higher in the break streams than in the middlings streams but a little lower in the ash of these streams, as shown in Table II. It is higher in the wheat and highest of all in the bran. With the exception of the second break stream, it increases with the number of the break stream and in the middlings streams with the number of the middlings stream. It is lower in the straight flour than the average in the break streams and higher than the average in the middlings streams. Swanson, Willard, and Fitz (1915) found a lower percentage of phosphorus in the straight flour than the average in the middlings streams, but they used a larger number of middlings streams; and as the phosphorus content increases with the number of the middlings stream this would account for the difference.

It is lower in the clear flour than in the average break streams, but higher than the average in the middlings streams.

Crude protein.—Protein averages higher in the break streams than in the middlings streams. It is lower in the wheat than in the average break streams and higher than in the average middlings streams. It is higher in the bran than in the wheat or the average middlings streams but lower than in the average break streams. With the exception of the second break, the protein increases in the break stream with the number of the break and in the middlings streams (with the exception of the second) with the number of the middlings streams. It is lower in the straight flour than in the clear flour and in both straight and clear flour, it is lower than in the average break stream and higher than in the average middlings stream.

The fat averaged lower in the middlings streams than in the break streams and lower in the straight flour than in the clear flour. The carbohydrates averaged higher in the middlings streams than in the break streams and higher in the straight flour than in the clear flour.

Iron-ash ratio—There appeared to be a correlation between the percentage of iron and of ash in the various streams, as these percentages are recorded in Table I and II. The ratio of Fe: ash was accordingly computed in the instance of each stream. The resulting values, recorded in the first column of data in Table III, establish the relative constancy of this ratio, which varies through comparatively narrow limits. The iron-ash ratio averages a little higher in the break streams than in the middlings streams. In the wheat the ratio equals the average ratio in the total streams, while in the bran the ratio equals the average ratio in the break streams. The ratio in the straight flour about equals the average ratio in the middlings streams; while the ratio in the clear flour lies between the ratio in the wheat and the average ratio in the break streams.

Iron-phosphorus ratio.—The iron-phosphorus ratio as shown in Table III averages higher in the break streams than in the middlings streams. It is higher in the wheat and highest of all in the bran. The ratio in the straight flour approaches the ratio in the average middlings streams; while the ratio in the clear flour approaches the average in the break streams.

Iron-calcium ratio.—The iron-calcium ratio, as shown in Table III, averages higher in the break streams than in the middlings streams. It is higher in the bran and highest in the wheat. It apparently increases in the break streams with the number of the

stream and in the middlings streams with the number of the stream. It is higher in the straight than in the clear flour. In the straight flour, it is lower than the average ratio in the break streams, and higher than the average ratio in the middlings streams. In the clear flour, it is lower than the average ratio in either the break or the middlings streams.

TABLE III

RATIOS OF SEVERAL CONSTITUENTS OF WHEAT, AND FLOUR STREAMS

	$\frac{Fe}{Ash}$	$\frac{Fe}{P}$	$\frac{Fe}{Ca}$	$\frac{Fe}{Mg}$	$\frac{Fe \times 10^4}{Protein}$
First break	0.00116	0.00470	0.0429	0.0145	0.536
Second break	.00103	.00436	.0570	.0140	.503
Third break	.00118	.00500	.0559	.0144	.584
Fourth break	.00112	.00470	.0604	.0130	.803
First middlings	.00086	.00396	.0218	.0162	.307
Second middlings	.00093	.00381	.0370	.0169	.323
Third middlings	.00099	.00376	.0250	.0169	.350
Fourth middlings	.00105	.00409	.0475	.0170	.388
Straight flour	.00098	.00379	.0439	.0157	.399
Clear flour	.00109	.00447	.0320	.0144	.606
Wheat	.00105	.00481	.0580	.0119	1.298
Bran	0.00113	0.00485	0.0570	0.0122	3.627

	$\frac{P}{Ash}$	$\frac{P}{Protein}$	$\frac{Ca}{Mg}$	$\frac{Ca}{P}$	$\frac{Mg}{P}$	$\frac{Ca}{Protein}$	$\frac{Mg}{Protein}$
First break	0.2460	0.0114	0.338	0.1095	0.3244	0.00125	0.00370
Second break	.2365	.0116	.245	.0766	.3120	.00088	.00360
Third break	.2354	.0117	.257	.0894	.3475	.00104	.00406
Fourth break	.2389	.0170	.216	.0778	.3607	.00133	.00616
First middlings	.2177	.0078	.743	.1813	.2440	.00141	.00189
Second middlings	.2449	.0085	.457	.1031	.2258	.00087	.00191
Third middlings	.2620	.0093	.675	.1504	.2229	.00140	.00208
Fourth middlings	.2567	.0095	.359	.0861	.2400	.00082	.00228
Straight flour	.2578	.0105	.359	.0864	.2409	.00091	.00254
Clear flour	.2432	.0136	.449	.1396	.3112	.00189	.00422
Wheat	.2180	.0271	.206	.0826	.4018	.00223	.01090
Bran	0.2330	0.0748	0.214	0.0851	0.3972	0.00636	0.02978

Iron-magnesium ratio.—The iron-magnesium ratio averages lower in the break streams than in the middlings streams. It is lower in the bran and lowest of all in the wheat. The constancy of this ratio in the individual break streams and in the individual middlings streams is of note. In general, there is much less variation in this ratio than in the iron-calcium ratio. The ratio in the straight flour is a little higher than the average ratio in the break streams and a little lower than the average in the middlings streams; while in the clear flour it is about the same as the average ratio in the break streams and lower than the average in the middlings streams. It is higher in the straight than in the clear

flour. The relatively uniform ratio of iron to magnesium is of interest because of the rôle of these elements in the metabolism of the wheat plant. Iron appears to be essential in carbohydrate metabolism. Its withdrawal from the nutrient solution occasions chlorosis and the resultant decrease in chlorophyl in stem and leaves in turn diminishes carbon fixation. Magnesium is the characteristic mineral constituent of chlorophyl, however. It might be anticipated that the structures of the wheat kernel which contain the most iron may also contain the most magnesium. The data resulting from this study are in accord with the metabolic relationship of these two elements.

Iron-protein ratio.—The iron-protein ratio averages higher in the break streams than in the middlings streams. It is higher in the wheat and highest of all in the bran. With the exception of the second break, it increases with the number of the break; while in the middlings streams, it increases with the number of the stream. In the straight flour, it approaches the average of the middlings streams; while in the clear flour, it approaches the average of the break streams.

Phosphorus-ash ratio.—The phosphorus-ash ratio averages a little higher in the middlings streams than in the break streams. It is higher in the straight flour than in the average of either the break or the middlings streams; while in the clear flour it is about the mean average of the break and the middlings streams. It is lower in the wheat than in the bran, and lower in both the wheat and the bran than in the average of either the break or middlings streams.

Phosphorus-protein ratio.—The phosphorus-protein ratio, as shown in Table III, is higher in the average break streams than in the average middlings streams. It is higher in the wheat and highest of all in the bran. There is a gradual increase in the ratio in the break streams with the number of the stream and in the middlings streams with the number of the stream. The ratio in the straight flour is lower than the average in the break streams and higher than the average in the middlings streams. It is higher in the clear flour than in the average of either the break or the middlings streams.

Calcium-phosphorus ratio.—The calcium-phosphorus ratio averages higher in the middlings streams than in the break streams. It is lower in the bran and lowest of all in the wheat. It is lower in the straight flour than the average in either the break or the

middlings streams; while in the clear flour it is higher than the average of either the break or the middlings streams.

Magnesium-phosphorus ratio.—The magnesium-phosphorus ratio averages higher in the break streams than in the middlings streams. It is higher in the bran and highest of all in the wheat. With the exception of the second break, it increases with the number of the break stream, but shows no regular change in the middling streams. In the clear flour, the ratio is lower than the average in the break streams and higher than the average in the middlings streams. In the straight flour, the ratio is lower than the average in the break streams and a little higher than the average in the middlings streams.

Calcium-protein ratio.—The calcium-protein ratio averages lower in the break streams than in the middlings streams. It is higher in the wheat and highest of all in the bran; and in the straight flour, it is lower than the average in either the break or middlings streams, while in the clear flour, it is higher than the average in either the break or middlings streams.

Magnesium-protein ratio.—The magnesium-protein ratio averages higher in the break streams than in the middlings streams. It is higher in the wheat and highest of all in the bran. With the exception of the second break, it increases with the number of the break stream; and in the middlings streams, increases with the number of the stream. In the straight flour, it is lower than the average in the break streams and higher than the average in the middlings streams. In the clear flour, it is lower than the average in the break streams and higher than the average of the middlings streams.

Summary

Iron, which is so necessary in the blood stream and which in wheat flour enters so readily into the metabolic process of the body and may be associated with the enzymic action of flour; calcium, which is essential in the building of the bony structures and which is associated with the occurrence of rickets; phosphorus, which is essential in the building of bony structures and which may be associated with the occurrence of rickets; and magnesium; protein; and fat, all average lower in the middlings streams than in the break streams and lower in the straight flour than in the clear flour. The best patent flours (made from the middlings streams) contain less of the nutritional constituents and also less of the constituents associated with vital phenomena than the so-called poorer grades of flour.

The iron averages only half as much in the middlings streams as in the break streams, and about one and one-half as much in the clear flour as in the straight flour. The iron-ash ratio is remarkably constant in all the different streams.

The iron-magnesium ratio is remarkably constant and especially so in the break streams and the middlings streams.

The iron-calcium ratio shows no such constancy as the iron-magnesium ratio. The calcium-magnesium ratio increases in the break streams with the number of the stream and in the middlings streams (with the exception of the third stream) with the number of the stream. This is in accordance with the ratios shown by Bailey to exist between these elements in proceeding from the poorer to the higher grades of flour.

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ESTIMATION OF AMINO ACIDS AND PROTEOLYTIC ACTIVITY IN WHEAT AND FLOUR

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In two papers, Swanson and Tague (1916, 1917) have described a method for the estimation of titratable nitrogen in flour by means of the Sörensen formol titration (1907) and have studied by this means the effect of the addition of certain substances to flour-water suspensions.

The present authors, prior to reading the accounts of this work, had developed a very similar method of titratable nitrogen estimation, which had been brought to conclusions that were so far different from those of Swanson and Tague as to be worth recording.

The procedure of Swanson and Tague was as follows: A given quantity of flour is mixed with ten times its weight of water treated with toluene to inhibit bacterial activity, and the suspension is shaken at frequent intervals for about an hour. After settling half an hour, it is filtered, in some cases having been kept in a thermostat to maintain a constant temperature of extraction.

The clear liquor is divided into four samples of 100 cc. each and duplicates are taken for each of the two tests. The first test is as follows: A specified quantity of thymolphthalein, and 10 cc. of formol neutralized to the same indicator are added, and the mixture is allowed to stand for 15 minutes. In the meantime the second process is carried out, viz, 100 cc. titrated with 0.05N baryta with phenolphthalein as indicator, the phenolpthalein going to a full rose color.

Proceeding with the first test, this is titrated also, in this case to a faint blue. The amount of amino nitrogen is calculated by multiplying the difference between the means of the titration figures by the factor 0.7.

The present authors carried out the determination as follows: 40 gm. of flour or kibbled wheat is extracted with 200 cc. distilled water. The distilled water, which was of very good quality, being obtained from a pure tin Hartley-Bourdillon still, was on occasion treated with toluene; but for ordinary experiments lasting, as will be seen later, for only two hours, errors were not found due to

bacterial action in its absence. When present, it did not affect the enzymic activities to be described.

The mixture is shaken continuously for 5 minutes, and then centrifuged off as rapidly as possible, 10 cc. is titrated with N/100 H_2SO_4 using methyl red as indicator, and titrating with an approximate color standard to pH 5.5.

Another 10 cc. is added to the solution of pure formol neutralized to phenolphthalein and the mixture is titrated against N/100 NaOH. The titration is here, also, taken up to a point where the indicator (phenolphthalein) shows a full rose color, an approximate color standard being used. The titration with acid reduces the extract to a constant pH at which no amino acid is ionized in either sense, so the sum of the two readings again gives the amino acid content (sum, as in this case the first titration is against acid). This value is multiplied by the factor 0.03854, which is obtained experimentally from a test on glycine, and gives the amino acid content as glycine—the usual way of reporting this figure. As this process is rather too short for the titration to be complete, this factor also takes into account this slight incompleteness. The reason for the shortness of the process will be seen later.

Swanson and Tague, in order to determine the best proportions in which to mix their flour and water, mixed their suspensions and then took out and filtered portions after varying times, and carried out analyses, thinking that the increase in titratable nitrogen was due to a gradual completion of the extraction. They claimed that their further results show that more titratable material is extracted at 37° C. than at 25° C., also that the titratable material in flour is extracted in an hour, and that extraction for another hour gives no apparent increase.

The authors observed that if the whole of the suspension was first centrifuged, these changes took place in the clear liquid, and they conclude that they are due, not to a further extraction but to proteolytic activity in the flour, flour which had been previously heated to destroy the enzymes showing little or no such change. Had the increase been due to a gradual extraction, there would have been no change when all the suspension had been first centrifuged, nor would the previous heating of the flour have had so marked an inhibiting effect.

Swanson and Tague's further observation on temperature may be interpreted as being due to the increased enzymic activity at the higher temperature.

The result obtained after an arbitrary time is not a measure of the initial amino acid in the flour; still less is that after an "infinite" time, i.e., when the enzymic changes have ceased.

In order to obtain a figure for the titratable nitrogen in the original flour, readings are taken at intervals during two hours on samples from the stock of centrifuged liquid, and it has been found that if the percentages of amino acid (as glycine) are plotted against the logarithmic time, a straight line is obtained which can be interpolated backwards, so that a value of the amino acid before any proteolysis has taken place can be obtained. The slope of this curve is a measure of the proteolytic activity of the flour.

A similar experiment works quite satisfactorily with wheat which has been first passed through a fine kibbler. The time is taken as from the first admixture of the flour with water.

Discussion of Swanson and Tague's Figures

If Swanson and Tague's figures for the increase of amino nitrogen in the unfiltered suspension are plotted in the manner used by the authors for the determination as described above, a straight line is obtained, which falls off sharply after the first hour, as they themselves state. There are not really enough points on the earlier part of the curves to show clearly the straight line relationship, but there can be no doubt that it is there.

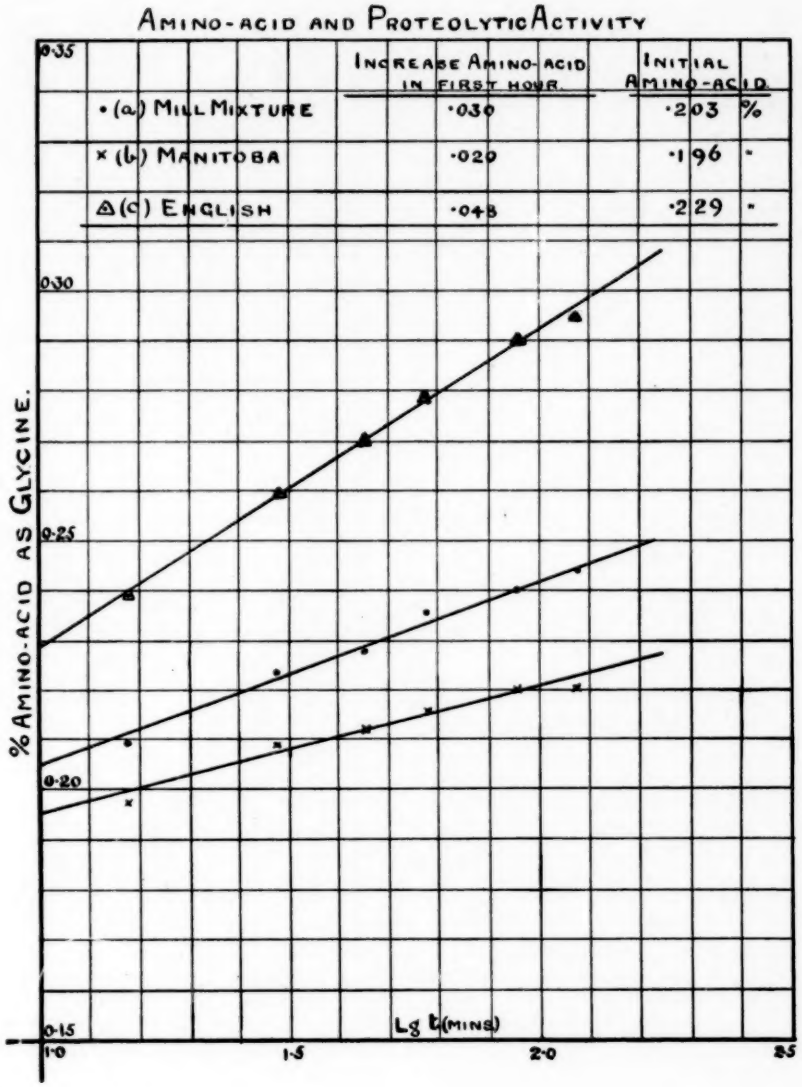
The law for this curve, which is of the type: $x = k \log t + a$ where x is the amino acid content and k and a are constants, does not in itself help to decide between the two theories of the phenomenon, as such relationship would probably occur in both cases.

Actual Results Obtained by Method Described

As examples of the use of the method, are given three curves taken on wheats as follows:

(a) A typical mill mixture.
(b) A Manitoba wheat.
(c) An English wheat.

It will be seen from these curves that the weak English wheat shows the steepest curve and the highest amino acid content, the mixture coming next, and the strong Manitoba wheat exhibiting very little proteolytic activity.


AMINO-ACID AND PROTEOLYTIC ACTIVITY
INCREASE AMINO-ACID IN FIRST HOUR.
INITIAL AMINO-ACID.
• (a) MILL MIXTURE ·030 ·203 %
× (b) MANITOBA ·020 ·196 "
△ (c) ENGLISH ·048 ·229 "
% AMINO-ACID AS GLYCINE.
0·35
0·30
0·25
0·20
0·15
1·0
1·5
2·0
2·5
Lg t (MINS)

Results

t (min.)	log T	cc. alkali N/100	cc. acid N/100	Total	% Glycine
Wheat (a).					
15	1.176	3.9	1.5	5.4	0.209
30	1.477	4.2	1.6	5.8	0.224
45	1.653	4.8	1.6	5.9	0.228
60	1.778	4.4	1.7	6.1	0.236
90	1.954	4.5	1.7	6.2	0.240
120	2.079	4.6	1.7	6.3	0.244
Wheat (b).					
15	1.176	3.7	1.4	5.1	0.197
30	1.477	3.9	1.5	5.4	0.209
45	1.653	4.0	1.5	5.5	0.212
60	1.778	4.1	1.5	5.6	0.216
90	1.954	4.2	1.5	5.7	0.220
120	2.079	4.2	1.5	5.7	0.220
Wheat (c).					
15	1.176	4.7	1.5	6.4	0.249
30	1.477	5.2	1.5	6.7	0.259
45	1.653	5.5	1.5	7.0	0.270
60	1.778	5.7	1.5	7.2	0.278
90	1.954	5.9	1.6	7.5	0.290
120	2.079	6.0	1.6	7.6	0.294

Summary of Results

A method for determining the amino acid content of flour and wheat is described, which, altho very similar to that of Swanson and Tague, is believed to give a truer figure for the amino acid content.

The method is extended to give a figure also for the proteolytic activity of the flour or wheat.

Swanson and Tague's views on the rate of extraction of flour in water are criticised.

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EFFECT OF CONCENTRATION ON VISCOSITY OF FLOUR SUSPENSIONS

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In view of the practical importance of the Sharp and Gortner test for the hydration capacity of gluten, the following notes underlying the theoretical basis, which was not fully discussed in the original paper, may possibly prove of interest.

Sharp and Gortner (1923) have shown that the viscosity of flour suspensions is related to the concentration in accordance with the following equation:

$$\log \eta = k \log c + a$$

where η is the viscosity of the suspension, c is the concentration, and k and a are constants. They associate k with the water absorbing capacity, and a with the quantity rather than the quality of the gluten.

On the basis of Einstein's (1906) equation, which may be written:

$$\eta = k' c + b$$

which assumes no change in hydration with concentration, and no electrical charge of the particles, we should expect the viscosity to increase much less rapidly than Sharp and Gortner have found it to do.

Von Smoluchowski (1916) has shown that an alteration in the constants only in Einstein's equation extends it to include shapes of particles other than the spherical. The discrepancy between these equations can only be due to a variation of the degree of hydration with concentration or to the influence of the electrical charge on the particles, with the possibility that both factors are involved. Hitherto it has been generally assumed that variation in the degree of hydration alone is entirely responsible for the anomaly, and this leads to the rather curious position of assuming an increased hydration (i.e., an increase in the size of water envelope) at high concentrations. Although it is difficult to believe that this could account for the entire phenomenon (on account of decreased ionization and the relatively smaller mean free path of the particles), it will be shown later that actually at very high

concentrations a small increase in the size of the water envelope probably occurs.

If it is assumed that the electrical charge on the particles alone is the cause of the anomaly, then since the forces between these vary as some power of the distance between them and as the distance between them is also as a power of the concentration, the variation in viscosity with concentration should vary as a power of the concentration.

The Sharp and Gortner equation may be written in the form

$$\eta = (\log {}^{-1}a)c^k \text{ whence } \frac{d\eta}{dc} = k(\log {}^{-1}a)c^{k-1}$$

which leads to the same conclusion. The slope of the curve will thus depend on the charge on the particles, and hence, presumably, on the water absorption capacity, as Sharp and Gortner originally suggested. Examination of large numbers of Sharp and Gortner curves for flours tested in these laboratories, of which Figures 1 and 2 are typical examples, shows a slight discrepancy from the straight line in all cases in the form of an upward bend at very high concentrations.

Loeb (1921) has shown (actually in the case of gelatin sols) that "the formation of aggregates out of isolated protein molecules, or ions, increases the viscosity," and it is probable that this aggregation accounts for the experimental departure from the Sharp and Gortner law. [See also work by Menz (1909)].

This increase in viscosity is probably due to the strong repulsive forces between similarly charged nuclei (now within one water envelope) and is a very early stage in the formation of a gel in which the viscosity is enormous in spite of a very low colloidal concentration.

To quote Loeb "We reach the conclusion that the gelatine solutions contain submicroscopic particles of solid jelly, i.e., micellae, which occlude relatively large quantities of water, whereby the relative volume occupied by the gelatine in solution is increased. . . ."

"These submicroscopic particles of solid jelly are the precursors of the continuous jelly to which the gelatine solution has a tendency to set."

Loeb, though working with gelatin, a much simpler colloid than flour, applies his results to proteins in general, and the phenomena are probably very similar in both cases, tho less marked in the case of the flour.

FIG I

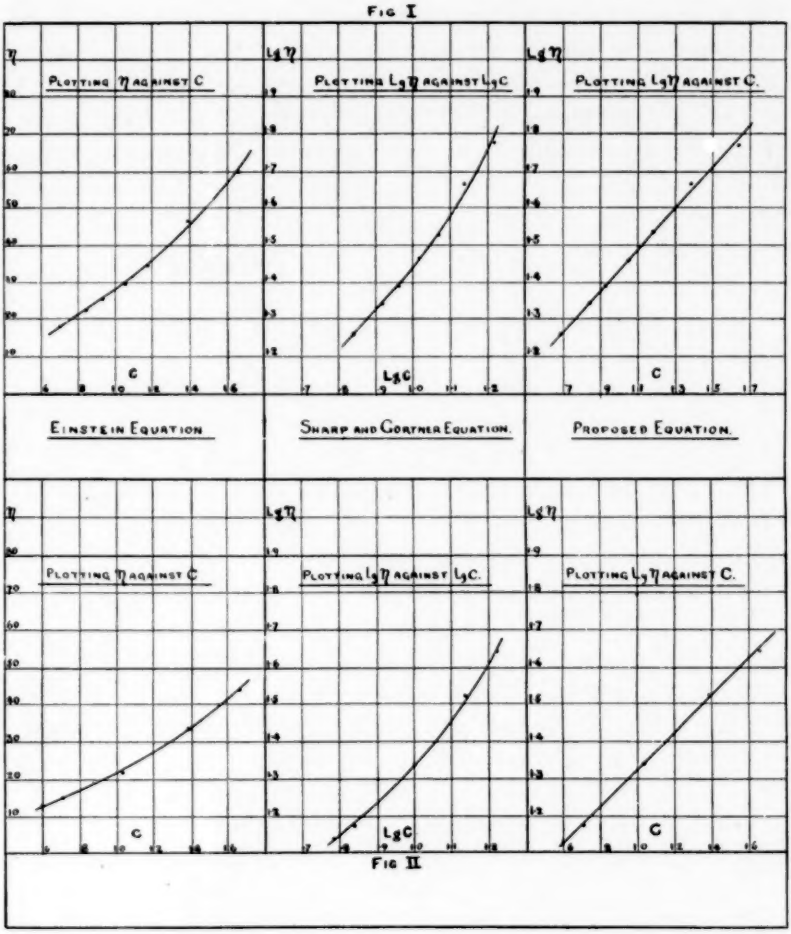

FIG II

The formation of these jelly precursors depends, as Loeb has shown, on a Donnan (1911) equilibrium between the particles and the medium. The reason for this is as follows: In a normal flour suspension, the protein being on the alkaline side of the isoelectric point [as shown by Bailey and Peterson, (1921) and also by Tague (1925) and as can be deduced from the pH-viscosity curves given by Henderson, Fenn, and Cohn (1919)], the calcium and other inorganic cations will be shared in equilibrium between the protein anions and the inorganic anions. For simplicity, only the case of the calcium ion [Ca^{++}] and the bivalent phosphate [HPO_4^{--}] ions will be considered. These ions are both diffusible and can enter and leave the suspended particles as equilibrium requires, whereas the protein anion cannot do so.

If a small (virtual) ionic diffusion takes place at constant temperature and volume in such a way that no external work is done (i.e., in a thermodynamically reversible manner), and if δn moles $Ca^{\cdot\cdot}$ and δn moles HPO_4^{--} pass into the suspended particle from the circumambient liquid, the work done can be equated to zero, or:

$$2\,\delta n\,RT \log \frac{[Ca^{\cdot\cdot}]e}{[Ca^{\cdot\cdot}]i} + 2\,\delta n\,RT \log \frac{[HPO_4^{--}]e}{[HPO_4^{--}]i} = O$$

or

$$[Ca^{\cdot\cdot}]e\ [HPO_4^{--}]e = [Ca^{\cdot\cdot}]i\ [HPO_4^{--}]i$$

where

$[Ca^{\cdot\cdot}]e$ is concentration of $Ca^{\cdot\cdot}$ outside particles
$[Ca^{\cdot\cdot}]i$ is concentration of $Ca^{\cdot\cdot}$ within particles
$[HPO_4^{--}]e$ is concentration of HPO_4^{--} outside particles
$[HPO_4^{--}]i$ is concentration of HPO_4^{--} within particles
R is gas constant
T is absolute temperature.

Unfortunately, the same process cannot be carried out for the undissociated molecules (see Donnan's paper already quoted), but in order for this state of equilibrium to be attained, it is clear that a diffusion of ions into the particles from the circumambient liquid must take place. That the diffusion must be inward is apparent from the fact that calcium hydrogen phosphate being soluble, it is likely to occur in the newly concentrated suspension, chiefly in the liquid phase. This will set up an increased osmotic pressure inside the particles, and water will have to diffuse inward to counteract this. It is this infusion of water that constitutes the formation of jelly precursors.

The curvature in the upper part of the Sharp and Gortner straight line, which has apparently a sound theoretical basis, makes it very difficult to obtain accurate determinations of the slope of the line such as are continually required in commercial flour analyses, and it has been found that the curve obtained after plotting log viscosity against concentration direct (of which the equation is, of course

$$\log \eta = k'' c + d$$

where k'' and d are constants), gives a good straight line in all cases. Loeb (loc. cit.) quotes Arrhenius as having found it advantageous to plot log (η/η') against concentration direct where η' is the viscosity of the medium) in his work on the viscosity of albumin, and states that he found good agreement with experiment under certain conditions, tho the applicability seems to have been

limited, probably owing to the difficulty of obtaining accurate viscosity measurements at high concentrations. The use of this equation justifies itself by its practical utility, though it is, of course, purely empirical, since on differentiation it shows that the viscosity varies as a constant raised to a power of the concentration.

Summary

The use of viscosity measurements of flour suspensions at different concentrations having already justified itself as a means of determining flour strength, the theoretical considerations underlying the equation adopted by Sharp and Gortner have been investigated. The physical significance which they attach to their constants and certain experimental discrepancies observed in actual practice, have been discussed and further elucidated, and an empirical formula, which is claimed to be of greater practical utility than the original expression, is put forward.

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CONVERSION TABLES FOR CALCULATING THE ABSORPTION OF FLOUR TO A 15.0% MOISTURE BASIS

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For some years it has been common practice to report all analytical data on flours to a uniform moisture basis, usually 13.5%. Recently the United States Government has set the maximum moisture content of flour at 15.0% as determined in vacuo at 100°C. It is probable, therefore, that in the future, 15.0% moisture (vacuo), rather than 13.5%, will be the basis on which analytical data will be reported.

In 1925, Meyer[1] published a table for computing absorption of flour at 13.5% when the moisture content and the absorption were known. This table has been recalculated, using the formula:

$$\text{Absorption (15.0)} = \frac{85 \times (\text{Abs.} + \text{Moist.})}{100 - \text{Moist.}} - 15$$

Several years experience has convinced us that a sample of flour at any moisture content (assuming, of course, that the flour was not damaged during drying) will have the same absorption when the absorption is calculated to a uniform moisture basis.

TABLE FOR CALCULATING ABSORPTION TO 15% MOISTURE

	Moisture of Flour as Received									
Absorption as received	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9
64.0	53.2	53.3	53.5	53.7	53.9	54.0	54.2	54.3	54.5	54.7
64.5	53.7	53.8	54.0	54.2	54.3	54.5	54.7	54.8	55.0	55.2
65.0	54.1	54.3	54.4	54.6	54.8	55.0	55.2	55.3	55.5	55.7
65.5	54.6	54.7	54.9	55.1	55 2	55.5	55.6	55.8	56.0	56.2
66.0	55.1	55.2	55.4	55.6	55.7	55 9	56.1	56.2	56.4	56.6
66.5	55.6	55.7	55.9	56.0	56.2	56.4	56.5	56.7	56.9	57.1
67.0	56.0	56.2	56.3	56.5	56.7	56 9	57.0	57.2	57.4	57.6
67.5	56.5	56.6	56.8	56.9	57.1	57.3	57.5	57 6	57.8	58.0
68.0	56.9	57.1	57.3	57.4	57.6	57.8	57.9	58.1	58.3	58.5
68.5	57.4	57.6	57.8	57.9	58.1	58.3	58.4	58.6	58.8	58.9
69.0	57.9	58.1	58.2	58.4	58.6	58 8	58.9	59.1	59.3	59.4
69.5	58.3	58.5	58.7	58.8	59.0	59 2	59.3	59 5	59.7	59.8
70.0	58.8	59.0	59.2	59.3	59.5	59.7	59.8	60 0	60.2	60.4
70.5	59.3	5	59.6	59.8	60.0	60.2	60.3	60.5	60.7	60.8
71.0	59.7	60.0	60.1	60.3	60.5	60.6	60.8	60.9	61.1	61.3
71.5	60.2	60.4	60.6	60.7	60.9	61.1	61.2	61.4	61.6	61.8
72.0	60.7	60.8	61.0	61.2	61.4	61.5	61.7	61.9	62.1	62.3
72.5	61.2	61.3	61.5	61.7	61.9	62.0	62.2	62.4	62 6	62.8
73.0	61.6	61.8	62.0	62.2	62.4	62.5	62.7	62.8	63.0	63.2
73.5	62.1	62.2	62.4	62.6	62.8	62.9	63.1	63.3	63.5	63.6
74.0	62.5	62.7	62.9	63.1	63.3	63.4	63.6	63.8	64.0	64.2

[1]Cereal Chemistry, 2:42-45. 1925.

TABLE FOR CALCULATING ABSORPTION TO 15% MOISTURE—*Continued*

Absorption as received	Moisture of Flour as Received									
	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9
64.0	54.8	55.0	55.2	55.4	55.6	55.8	55.9	56.1	56.3	56.5
64.5	55.3	55.5	55.7	55.8	56.0	56.2	56.4	56.6	56.7	56.9
65.0	55.8	56.0	56.2	56.3	56.5	56.7	56.9	57.1	57.2	57.4
65.5	56.3	56.5	56.7	56.8	57.0	57.2	57.3	57.5	57.7	57.9
66.0	56.9	57.0	57.2	57.3	57.5	57.7	57.8	58.0	58.2	58.4
66.5	57.3	57.4	57.6	57.8	58.0	58.2	58.3	58.5	58.6	58.8
67.0	57.7	57.9	58.1	58.3	58.4	58.6	58.8	59.0	59.1	59.3
67.5	58.2	58.4	58.6	58.7	58.9	59.1	59.2	59.4	59.6	59.8
68.0	58.7	58.8	59.0	59.2	59.4	59.6	59.7	59.9	60.1	60.3
68.5	59.1	59.3	59.5	59.7	59.9	60.1	60.2	60.4	60.5	60.7
69.0	59.6	59.8	60.0	60.2	60.3	60.5	60.7	60.9	61.0	61.2
69.5	60.1	60.3	60.5	60.6	60.8	61.0	61.2	61.3	61.5	61.7
70.0	60.6	60.7	60.9	61.1	61.3	61.5	61.6	61.8	62.0	62.2
70.5	61.0	61.2	61.4	61.6	61.8	61.9	62.1	62.3	62.4	62.6
71.0	61.5	61.7	61.9	62.1	62.2	62.4	62.6	62.8	63.0	63.1
71.5	62.0	62.2	62.4	62.5	62.7	62.9	63.1	63.2	62.4	63.6
72.0	62.4	62.6	62.8	63.0	63.2	63.3	63.5	63.7	63.9	64.1
72.5	62.9	63.1	63.3	63.5	63.7	63.8	64.0	64.2	64.4	64.5
73.0	63.3	63.5	63.7	63.9	64.1	64.3	64.5	64.7	64.8	65.0
73.5	63.8	64.0	64.2	64.4	64.6	64.8	64.9	65.1	65.3	65.5
74.0	64.3	64.5	64.7	64.9	65.1	65.2	65.4	65.6	65.8	66.0

TABLE FOR CALCULATING ABSORPTION TO 15% MOISTURE—*Continued*

Absorption as received	Moisture of Flour as Received									
	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.8	
62.0	54.7	54.9	55.1	55.2	55.4	55.6	55.7	55.9	56.1	56.3
62.5	55.2	55.4	55.5	55.7	55.9	56.1	56.2	56.4	56.6	56.8
63.0	55.7	55.8	56.0	56.2	56.4	56.6	56.7	56.9	57.1	57.3
63.5	56.1	56.3	56.5	56.7	56.8	57.0	57.2	57.4	57.6	57.8
64.0	56.6	56.8	57.0	57.1	57.3	57.5	57.7	57.9	58.0	58.2
64.5	57.1	57.3	57.5	57.6	57.8	58.0	58.2	58.3	58.5	58.7
65.0	57.6	57.8	57.9	58.1	58.3	58.5	58.7	58.8	59.0	59.2
65.5	58.0	58.2	58.4	58.6	58.8	59.0	59.1	59.3	59.5	59.7
66.0	58.5	58.7	58.9	59.1	59.3	59.5	59.6	59.8	60.0	60.2
66.5	59.0	59.2	59.4	59.6	59.8	60.0	60.1	60.3	60.5	60.7
67.0	59.5	59.6	59.8	60.0	60.2	60.4	60.6	60.8	60.9	61.1
67.5	60.0	60.1	60.3	60.5	60.7	60.9	61.1	61.3	61.4	61.6
68.0	60.4	60.6	60.8	61.0	61.2	61.4	61.6	61.7	61.9	62.1
68.5	60.9	61.1	61.3	61.5	61.7	61.9	62.0	62.2	62.4	62.6
69.0	61.4	61.6	61.8	62.0	62.2	62.4	62.5	62.7	62.9	63.1
69.5	61.9	62.1	62.2	62.4	62.6	62.8	63.0	63.2	63.4	63.5
70.0	62.4	62.6	62.8	62.9	63.1	63.3	63.4	63.6	63.8	64.0
70.5	62.8	63.0	63.2	63.4	63.6	63.8	63.9	64.1	64.3	64.5
71.0	63.3	63.5	63.7	63.9	64.1	64.3	64.4	64.6	64.8	65.0
71.5	63.8	64.0	64.2	64.4	64.6	64.8	64.9	65.1	65.3	65.5
72.0	64.3	64.4	64.6	64.8	65.0	65.2	65.3	65.5	65.7	65.9

TABLE FOR CALCULATING ABSORPTION TO 15% MOISTURE—*Continued*

Absorption as received	Moisture of Flour as Received									
	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9
60.0	54.5	54.7	54.9	55.1	55.2	55.4	55.6	55.8	55.9	56.1
60.5	55.0	55.2	55.4	55.5	55.7	55.9	56.1	56.3	56.4	56.6
61.0	55.5	55.6	55.8	56.0	56.2	56.4	56.6	56.8	56.9	57.1
61.5	56.0	56.1	56.3	56.5	56.7	56.9	57.0	57.2	57.4	57.6
62.0	56.5	56.6	56.8	57.0	57.2	57.4	57.5	57.7	57.9	58.1
62.5	57.0	57.1	57.3	57.5	57.7	57.9	58.0	58.2	58.4	58.6
63.0	57.4	57.6	57.8	58.0	58.2	58.4	58.5	58.7	58.9	59.1
63.5	57.9	58.1	58.3	58.4	58.6	58.8	59.0	59.2	59.4	59.6
64.0	58.4	58.6	58.8	58.9	59.1	59.3	59.5	59.7	59.9	60.1
64.5	58.9	59.0	59.2	59.4	59.6	59.8	59.9	60.1	60.3	60.5
65.0	59.4	59.5	59.7	59.9	60.1	60.3	60.4	60.6	60.8	61.0
65.5	59.8	60.0	60.2	60.4	60.6	60.8	60.9	61.1	61.3	61.5
66.0	60.3	60.5	60.7	60.9	61.1	61.3	61.4	61.6	61.8	62.0
66.5	60.8	61.0	61.2	61.3	61.5	61.7	61.9	62.1	62.3	62.5
67.0	61.3	61.5	61.7	61.8	62.0	62.2	62.4	62.6	62.8	63.0
67.5	61.8	61.9	62.1	62.3	62.5	62.7	62.9	63.1	63.3	63.5
68.0	62.3	62.4	62.6	62.8	63.0	63.2	63.4	63.6	63.8	64.0
68.5	62.7	62.9	63.1	63.3	63.5	63.7	63.8	64.0	64.2	64.4
69.0	63.2	63.4	63.6	63.7	63.9	64.1	64.3	64.5	64.7	64.9
69.5	63.7	63.9	64.1	64.3	64.4	64.6	64.8	65.0	65.2	65.4
70.00	64.2	64.4	64.6	64.7	65.0	65.1	65.3	65.5	65.7	65.9

TABLE FOR CALCULATING ABSORPTION TO 15% MOISTURE—*Continued*

Absorption as received	Moisture of Flour as Received									
	13.0	13.1	13.2	13.3	13.4	13.5	13.6	13.7	13.8	13.9
58.0	54.4	54.5	54.7	54.9	55.1	55.2	55.4	55.6	55.8	56.0
58.5	54.9	55.0	55.2	55.4	55.6	55.7	55.9	56.1	56.3	56.5
59.0	55.3	55.5	55.7	55.9	56.0	56.2	56.4	56.6	56.8	56.9
59.5	55.8	56.0	56.2	56.3	56.5	56.7	56.9	57.1	57.3	57.4
60.0	56.3	56.4	56.6	56.8	57.0	57.2	57.4	57.6	57.7	57.9
60.5	56.8	56.9	57.1	57.3	57.5	57.7	57.9	58.1	58.2	58.4
61.0	57.3	57.4	57.6	57.8	58.0	58.2	58.4	58.5	58.7	58.9
61.5	57.8	57.9	58.1	58.3	58.5	58.7	58.8	59.0	59.2	59.4
62.0	58.3	58.4	58.6	58.8	59.0	59.2	59.3	59.5	59.7	59.9
62.5	58.8	58.9	59.1	59.3	59.5	59.7	59.8	60.0	60.2	60.4
63.0	59.2	59.4	59.6	59.8	60.0	60.2	60.3	60.5	60.7	60.9
63.5	59.7	59.9	60.1	60.3	60.5	60.7	60.8	61.0	61.2	61.4
64.0	60.2	60.4	60.6	60.8	61.0	61.2	61.3	61.5	61.7	61.9
64.5	60.7	60.9	61.1	61.3	61.5	61.7	61.8	62.0	62.2	62.4
65.0	61.2	61.3	61.5	61.7	61.9	62.1	62.3	62.5	62.7	62.9
65.5	61.7	61.8	62.0	62.2	62.4	62.6	62.8	63.0	63.2	63.4
66.0	62.2	62.3	62.5	62.7	62.9	63.1	63.3	63.5	63.7	63.9
66.5	62.7	62.8	63.0	63.2	63.4	63.6	63.8	64.0	64.2	64.4
67.0	63.2	63.3	63.5	63.7	63.9	64.1	64.3	64.5	64.7	64.9
67.5	63.7	63.8	64.0	64.2	64.4	64.6	64.8	65.0	65.2	65.4
68.0	64.2	64.3	64.5	64.7	64.9	65.1	65.3	65.5	65.7	65.9

TABLE FOR CALCULATING ABSORPTION TO 15% MOISTURE—*Continued*

Absorption as received	Moisture of Flour as Received									
	14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8	14.9
56.0	54.2	54.4	54.6	54.8	54.9	55.1	55.3	55.5	55.6	55.8
56.5	54.7	54.9	55.1	55.3	55.4	55.6	55.8	56.0	56.1	56.3
57.0	55.2	55.4	55.6	55.8	55.9	56.1	56.3	56.5	56.6	56.8
57.5	55.7	55.9	56.1	56.3	56.4	56.6	56.8	57.0	57.1	57.3
58.0	56.2	56.3	56.5	56.7	56.9	57.1	57.3	57.4	57.6	57.8
58.5	56.6	56.8	57.0	57.2	57.4	57.6	57.8	57.9	58.1	58.3
59.0	57.1	57.3	57.5	57.7	57.9	58.1	58.3	58.4	58.6	58.8
59.5	57.6	57.8	58.0	58.2	58.4	58.6	58.7	58.9	59.1	59.3
60.0	58.1	58.3	58.5	58.7	58.9	59.1	59.2	59.4	59.6	59.8
60.5	58.6	58.8	59.0	59.2	59.4	59.6	59.7	59.9	60.1	60.3
61.0	59.1	59.3	59.5	59.7	59.9	60.1	60.2	60.4	60.6	60.8
61.5	59.6	59.8	60.0	60.2	60.4	60.6	60.7	60.9	61.1	61.3
62.0	60.1	60.3	60.5	60.7	60.9	61.0	61.2	61.4	61.6	61.8
62.5	60.6	60.8	61.0	61.2	61.4	61.5	61.7	61.9	62.1	62.3
63.0	61.1	61.3	61.5	61.7	61.9	62.0	62.2	62.4	62.6	62.8
63.5	61.6	61.8	62.0	62.2	62.4	62.5	62.7	62.9	63.1	63.3
64.0	62.1	62.3	62.5	62.7	62.9	63.0	63.2	63.4	63.6	63.8
64.5	62.6	62.8	63.0	63.2	63.3	63.5	63.7	63.9	64.1	64.3
65.0	63.1	63.3	63.5	63.6	63.8	64.0	64.2	64.4	64.6	64.8
65.5	63.6	63.8	63.9	64.1	64.3	64.5	64.7	64.9	65.1	65.3
66.0	64.1	64.3	64.4	64.6	64.8	65.0	65.2	65.4	65.6	65.8

TABLE FOR CALCULATING ABSORPTION TO 15% MOISTURE—*Concluded*

Absorption as rec'd	Moisture of Flour as Received										
	15.0	15.1	15.2	15.3	15.4	15.5	15.6	15.7	15.8	15.9	16.0
54.0	54.0	54.2	54.4	54.6	54.8	55.0	55.2	55.4	55.6	55.8	56.0
54.5	54.5	54.7	54.9	55.1	55.3	55.5	55.7	55.9	56.1	56.3	56.5
55.0	55.0	55.2	55.4	55.6	55.8	56.0	56.2	56.4	56.6	56.8	57.0
55.5	55.5	55.7	55.9	56.1	56.3	56.5	56.7	56.9	57.1	57.3	57.5
56.0	56.0	56.2	56.4	56.6	56.8	57.0	57.2	57.4	57.6	57.8	58.0
56.5	56.5	56.7	56.9	57.1	57.3	57.5	57.7	57.9	58.1	58.3	58.5
57.0	57.0	57.2	57.4	57.6	57.8	58.0	58.2	58.4	58.6	58.8	59.0
57.5	57.5	57.7	57.9	58.1	58.3	58.5	58.7	58.9	59.1	59.3	59.5
58.0	58.0	58.2	58.4	58.6	58.8	59.0	59.2	59.4	59.6	59.8	60.0
58.5	58.5	58.7	58.9	59.1	59.3	59.5	59.7	59.9	60.1	60.3	60.5
59.0	59.0	59.2	59.4	59.6	59.8	60.0	60.2	60.4	60.6	60.8	61.0
59.5	59.5	59.7	59.9	60.1	60.3	60.5	60.7	60.9	61.1	61.3	61.5
60.0	60.0	60.2	60.4	60.6	60.8	61.0	61.2	61.4	61.6	61.8	62.0
60.5	60.5	60.7	60.9	61.1	61.3	61.5	61.7	61.9	62.1	62.3	62.5
61.0	61.0	61.2	61.4	61.6	61.8	62.0	62.2	62.4	62.6	62.8	63.0
61.5	61.5	61.7	61.9	62.1	62.3	62.5	62.7	62.9	63.1	63.3	63.5
62.0	62.0	62.2	62.4	62.6	62.8	63.0	63.2	63.4	63.6	63.8	64.0
62.5	62.5	62.7	62.9	63.1	63.3	63.5	63.7	63.9	64.1	64.3	64.5
63.0	63.0	63.2	63.4	63.6	63.8	64.0	64.2	64.4	64.6	64.8	65.0
63.5	63.5	63.7	63.9	64.1	64.3	64.5	64.7	64.9	65.1	65.3	65.5
64.0	64.0	64.2	64.4	64.6	64.8	65.0	65.2	65.4	65.6	65.8	66.0

NOTES

"A Study of the Effect of Heat Upon Wheat and Flour, Especially in Relation to Strength" is the title of a thesis presented to the University of London by Douglas W. Kent-Jones in September, 1926. It includes a discussion of the results of heating wheat to comparatively high temperatures (as judged by American milling practices) for varying lengths of time, as recorded in terms of the characteristics of bread baked from the resulting flour, together with other properties of the flour, including imbibitional capacity, protein fractions, viscosity of protein solutions, proteolytic activity, diastatic activity, and gas production in fermenting doughs. The scope of the study is somewhat outside of the usual range of investigations in milling technology, and several possibilities are suggested by the results of this research.

"The A. B. C. of Hydrogen Ion Control" published by the La Motte Chemical Products Company, of Baltimore, Maryland, appeared in December, 1926. This includes a discussion of the meaning of hydrogen-ion concentration and pH values in simple language. The applications of hydrogen-ion determinations and control in various industries are indicated. Among the industries that are thus covered are: sugar manufacture and refining, food canning, flour, dough, bread, crackers, dyes, leather, and candy. The significance of H-ion control in chemical analysis is also stressed. The principle of the "comparator" is then described.